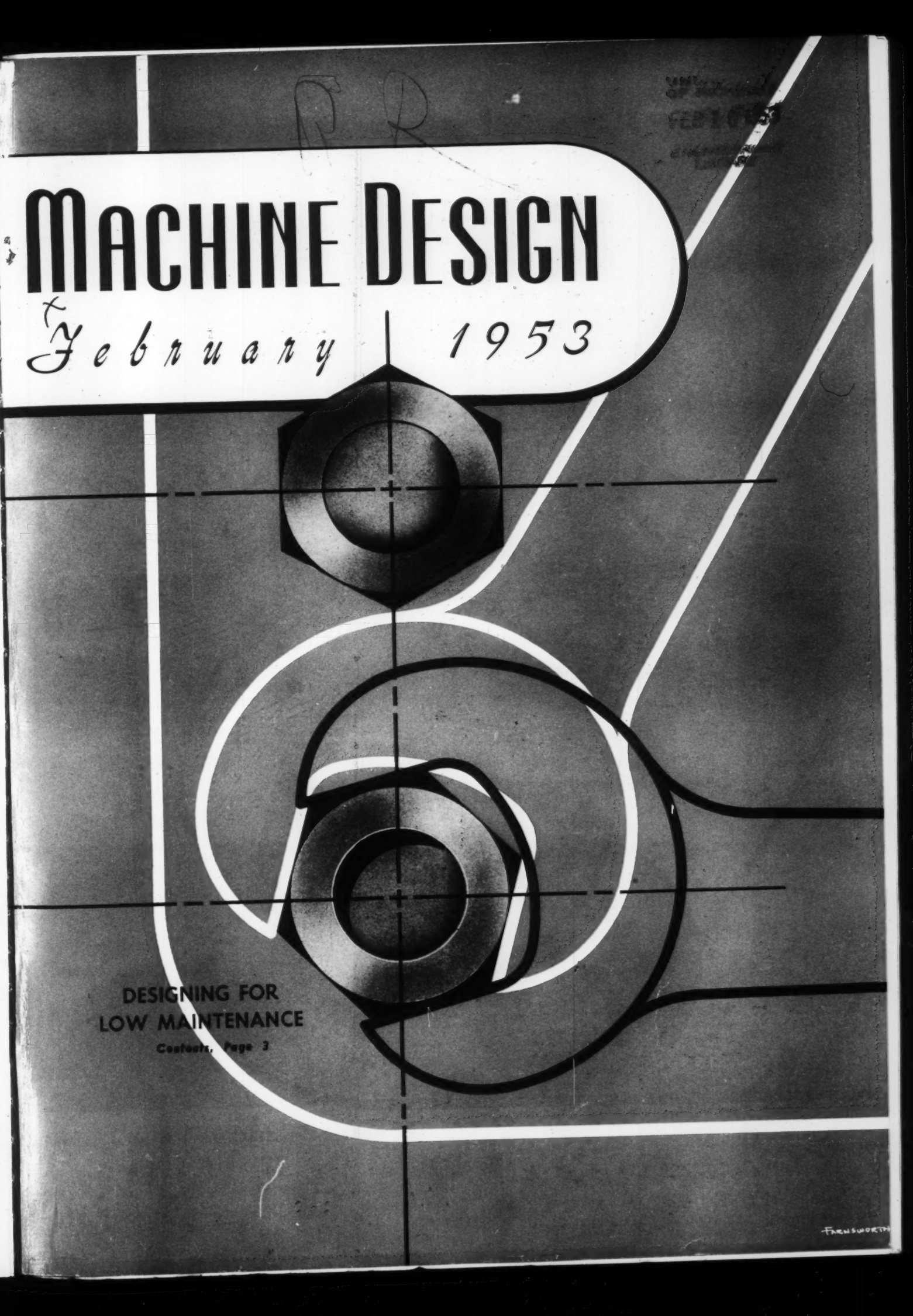
MACHINE DESIGN

February 1953



DESIGNING FOR LOW MAINTENANCE

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CUTLER·HAMMER

MOTOR CONTROL

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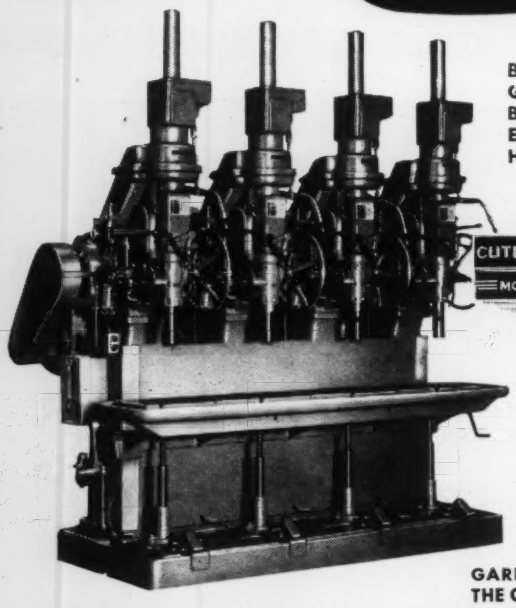
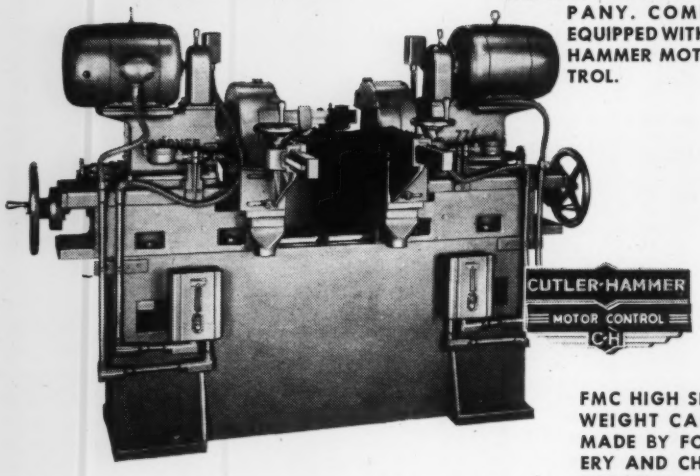
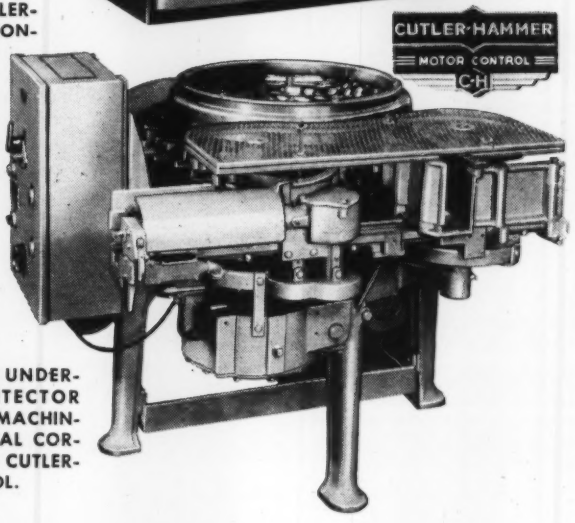


BARNESDRIL FOUR SPINDLE GANG DRILL MADE BY THE BARNES DRILL CO. FULLY EQUIPPED WITH CUTLER-HAMMER CONTROL.

3 TON "STORE CONDITIONER," ONE MODEL IN A COMPLETE LINE OF AIR CONDITIONING UNITS MADE BY U. S. AIR CONDITIONING CORPORATION. CUTLER-HAMMER CONTROL EQUIPMENT IS STANDARD.



GARDNER GRINDER MADE BY THE GARDNER MACHINE COMPANY. COMPLETELY EQUIPPED WITH CUTLER-HAMMER MOTOR CONTROL.



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When *name* becomes a *mark* of *merit*

In every field there are a few manufacturers who enjoy a great advantage. Their name or trademark on a product immediately identifies the product *as superior*. Their mark is taken as an assurance of unusual satisfaction to the product's user. This ready and unfailing association of name with merit is a tremendous commercial advantage . . . one its owners justly guard with care. But never to be overlooked in this linking of *name* and *quality* is the constant coupling of *product* and *satisfaction*. Never to be overlooked is that any company seeking to retain its leadership *cannot* permit the association to be broken. Such leaders therefore exert scrupulous and exacting care over every element entering the product . . . over every detail influencing product performance in the hands of the user.

It must be evident then that when leading machinery manufacturers continuously and repeatedly select Cutler-Hammer Motor Control for their machines, they do so but for one reason. And that reason is a *good* reason for *you* to specify Cutler-Hammer Motor Control for your machines as well. CUTLER-HAMMER, Inc., 1310 St. Paul Ave., Milwaukee 1, Wis. *Associate:* Canadian Cutler-Hammer, Ltd., Toronto, Ontario.

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February 1953, Vol. 25—No. 2

THE PROFESSIONAL JOURNAL FOR ENGINEERS AND DESIGNERS

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Over the Board

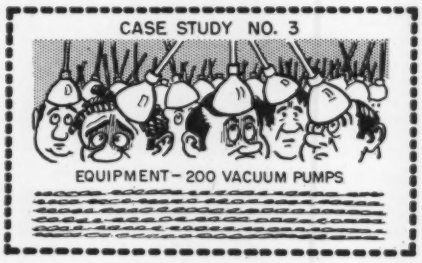
No Ivory Tower Here

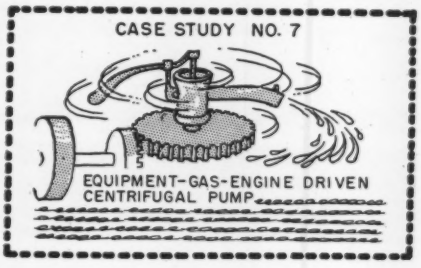
The old idea that our colleges are far removed from the practical world of engineering is due for some revision. A new motor design course being offered by Case Institute of Technology gives electrical engineering students a unique opportunity to relate theory and practice. Under the new plan small groups of students will work together in designing motors from one to 7½ hp. The motors will be built to the students' specifications by Robbins & Myers Inc., at no charge, and returned to Case where the students will check their work by actual tests, the motors then becoming the property of the college. This sort of co-operation between a college and a manufacturer sets an example that might well be followed in other areas of engineering design.

This Month's Cover

The finished covers that you see on MACHINE DESIGN do not always, like Minerva, spring full-panoplied from the brow of their creator. Thus, how to symbolize in an effective design the theme of this month's lead article "Designing for Low Maintenance" called for several conferences between editors and artists. George Farnsworth's simple but pleasing design illustrating one of the principal tools of maintenance finally won out.

Incidentally, George's illustrations in the article itself (Page 114) were selected from several





ideas submitted by our artists. Some of the earlier sketches seem too good for oblivion, so we are reproducing a selection by Pat Dwyer which we think may give you a chuckle or two.

Descriptive Writing

As engineer-editors we are often told that we should render the technical jargon of engineering into common, everyday language. The following nontechnical description of a well-known pair of machine parts has gone the rounds many times but is worth repeating in the foregoing connection. It is reported to be the work of a co-ed who took a course in machine design and turned in this answer on an assignment: "A bolt is a thing like a stick of hard metal such as iron with a square bunch on one end and a lot of scratching wound around the other end. A nut is just like a bolt only opposite, being a hole in a little square bunch of iron sawed off short, with wrinkles around inside the hole."

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Published by
THE PENTON PUBLISHING COMPANY

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Also publisher of
Steel • Foundry • New Equipment Digest

Published on the seventh of each month. Subscription in the United States and possessions, Canada, Cuba, Mexico, Central and South America: One year $10. Single copies, $1.00. Other countries one year, $15.

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Acceptance under Act of June 5, 1934. Authorized July 20, 1934.

CCA NBP MPA

February 1953

Reduced Maintenance—A Challenge!

MAINTENANCE is a problem confronting all users of machines—in the factory, office, laboratory, farm and home. The aspects of machine maintenance, however, are all too seldom considered by the designer in spite of their tremendous effects. Not only are the sales of appliances, automobiles, office machines, etc., directly affected by the maintenance-free service life afforded, but the very selling price of such machines in turn is to a high degree affected by the maintenance costs on the production machines utilized in their manufacture.

According to recent figures, American industry expended over eight and one-half billions of dollars on maintenance during 1948, a startling figure when it is considered that a substantial portion of this amount covers machinery upkeep. From recorded data, it has been found that maintenance costs in many companies exceed net profits; that as production capacity and volume increase, maintenance costs increase to a greater degree than net profits. The result is actually higher unit costs for items of manufacturing burden, the opposite of general belief. Not accounted for in these figures, however, are the down-time losses involved!

Because design plays a key role in this area of service-free life of machines, it behooves the designer to take serious note. Much can be done. Careful study of basic operational problems, environmental conditions, simplicity of upkeep, etc., can result in tremendous savings in time, labor and materials. As suggested in the lead article in this issue, engineering management holds the key to the problem—a little effort will unlock the door to results of unprecedented economic importance!

H. L. Dolz

ASSOCIATE EDITOR

Designing for Low

How improved operation, increased safety and reduced costs can be effected through design for minimum maintenance

By H. A. Bolz

Head, Department of General Engineering
Purdue University
Lafayette, Indiana

IT HAS BEEN said that "Research gets things started but it takes maintenance to keep them going"—and the designer may wonder just where he fits into the scheme of things. Actually it can be shown that it takes good design to get things started *right* and it takes good design to keep things going *economically,* that is, with a minimum of costly maintenance.

Considering maintenance, the designer can play a star dual-role in reducing costs. He can design so that

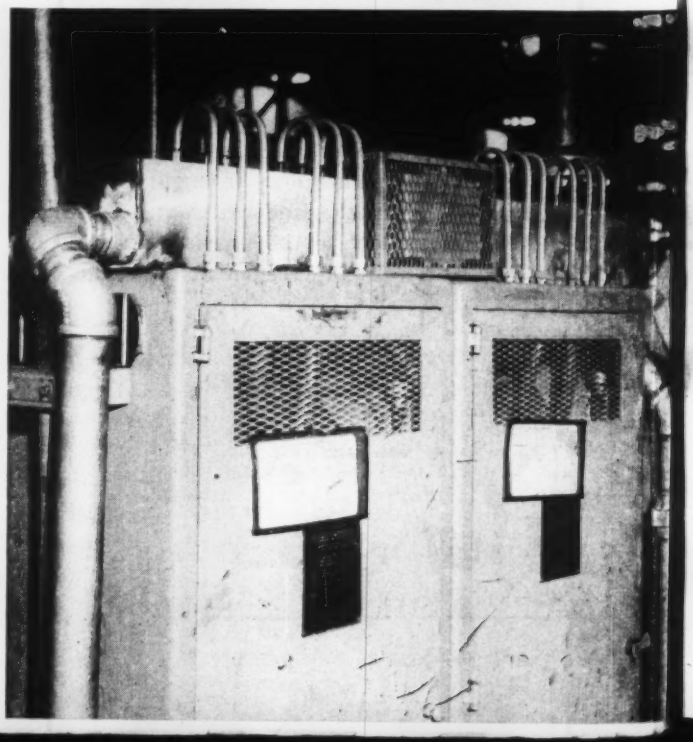
1. A minimum of maintenance will be required.
2. Any necessary maintenance is as simple and safe to perform as possible.

Minimum maintenance cost must be one of the prime objectives of every design along with satisfactory functioning, ease of operation, long life and sales appeal. Maintenance has too long been considered to be a necessary evil and industrial family skeleton hidden in the closet of factory burden. The price of maintaining equipment that has been designed inadequately or incorrectly includes more than the cost of the labor and materials required to perform the maintenance functions. Total maintenance costs also include

1. Down-time costs in loss of production or services.
2. Scrap or accident costs caused by malfunction preceding maintenance attention.
3. Cost of modification made by mechanics to facilitate maintenance.
4. Engineering cost of redesign.
5. Cost of parts and fabrication to produce a new design.
6. Loss of worker efficiency and cost of accidents induced by safety hazards.

In some cases the total annual maintenance cost for a poorly designed machine exceeds the original cost of the machine itself. (See Case Study No. 1). In many such instances the actual expenses are really much greater than is realized because maintenance cost analyses do not always include such factors as down-time losses and the cost of engineering redesign. In one particular case, five hydraulically actuated machines were designed and built for a semiautomatic finishing process involving a lubricant which takes part in producing the finish. Because of the faulty design the hydraulic fluid became contaminated by the lubricant causing damage in the control valves

Fig. 1—Redesign to include sight inspection of coolant on these induction hardening power units eliminated failures from plugged lines



Maintenance

CASE STUDY NO. 1

Faulty design results in annual maintenance cost exceeding original cost.

Equipment:
Paint drying oven.

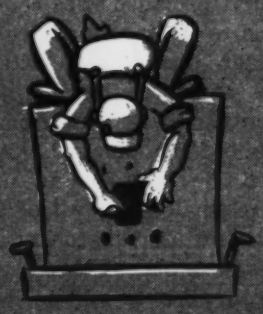
Purchase Price:
$1700.

Maintenance Cost First Year:
$2080.

Nature of Failure:
Oxidation of oil in bronze sleeve bearings mounted within the baking chamber necessitated frequent dismantling and cleaning.

Emergency Modification:
Bronze bushings were replaced by roller bearings, reducing annual maintenance cost to $225.

Proper Original Design Suggested:
Mount bearings outside the oven.



of the hydraulic pump. The annual maintenance cost for the five machines resulting from this damage was $6000. The original cost of the five machines was $8000. A revision in the construction of the machines to isolate the hydraulic system was made at a cost of $1300 and currently an expensive redesign is under way to eliminate all possible source of this trouble. Certainly the total cost involved in correcting this first design combined with the maintenance costs will greatly exceed the original price of the machines.

Recognition of the Problem: It is recognized that most designers in the current course of industrial progress are becoming increasingly maintenance minded. Of the many plant, safety and maintenance engineers who were consulted concerning data for this article a gratifying percentage expressed satisfaction with the growing consideration being given by the designers of modern machines and equipment. Nevertheless, much progress must still be made in this direction as evidenced in the sample collection of case studies and examples cited in this article. It is obvious that the designer cannot be blamed with any justice for all maintenance difficulties encountered in mechanical equipment. He often finds it impossible to get all of the facts and data concerning the job at hand and has to make assumptions. He sometimes (frequently, these days) finds the proper materials or parts unavailable and is obliged to make substitutions which he may know will lead to trouble. He has little control over misapplication, unnecessary abuse and overload, harmful environmental location, lack of adequate preventive maintenance and servicing, etc. Nevertheless, it is only by facing squarely his full responsibility in producing "maintenance-free" designs and recognizing what he must do to discharge this responsibility that he can contribute his utmost to the reduction of maintenance costs and the increase of productivity.

In analyzing the designer's responsibility for designing machines for minimum maintenance, it may prove useful to investigate the answers to the questions: (1) What constitutes good design from the maintenance standpoint?, and (2) How can minimum-maintenance designs be assured?

What is Good Design? Good design from the maintenance standpoint is design that will produce a device or process that: (1) Is easy and safe to move and install, set up, operate, adjust, inspect and check, lubricate, replace and repair parts, clean and keep clean, and paint; (2) will not break down or fail to function properly because of failure of parts, faulty lubrication, inadequate cooling, changes in adjustment, or action of environmental factors; and (3) will afford maximum protection to machine, product, and operator in event of breakdown.

Equipment that is not *easy and safe to move, install, and set up* usually develops a history of high maintenance expense and a reputation for poor design. Emergency repairs on such equipment are awkward and unsafe to make and are soon recognized by maintenance crews as such with the result that repair work proceeds even more slowly than necessary. Such apparently minor factors as wrench clearance and pinch points where fingers can be injured need careful consideration by the designer—not only for the sake of safety but for the sake of keeping up the morale of the maintenance staff and expediting their work. A machine that is *difficult to operate* because of poor design and placement of controls, insufficient lighting, annoying fumes, heavy forces required, etc., induces fatigue, discomfort, and ill will on the part of the operator. Such conditions

never fail to bring on accidents harmful to the operator and costly in maintenance on the equipment. It is in this area of designing machines for ease of operation that the designer can make a major contribution toward the reduction of maintenance costs for here he has control of the very first step in preventive maintenance.

Inasmuch as practically all equipment requires periodic *inspection* and *checking* as another step in preventive maintenance, the designer must give particular attention to this important function. *Fig.* 1 shows a set of capacitors and transformers of an induction hardening unit provided with cooling water discharge lines exposed to show at a glance the flow of the coolant from each line. These external pipes were installed only after the loss of several transformers and considerable costly downtime resulted when concealed lines became plugged. As another example, most modern television sets are unreasonably difficult to inspect, requiring removal of the entire unit in an operation that often adds to any existing damage unless extreme care and skill are used. If this type of design were applied to all of the equipment used in producing television sets the resulting maintenance costs would raise the price of the product beyond the reach of the public.

Following inspection and checking comes the occasional necessity of *replacing parts* and here, too, the designer has a responsibility. It may be simple enough to check the bearings and windings of an electric motor. However, if the end bells must be removed by being driven off with a lead hammer, as is the case with at least one popular make of motor, the resulting brinelling of the ball bearings will still keep the maintenance costs high.

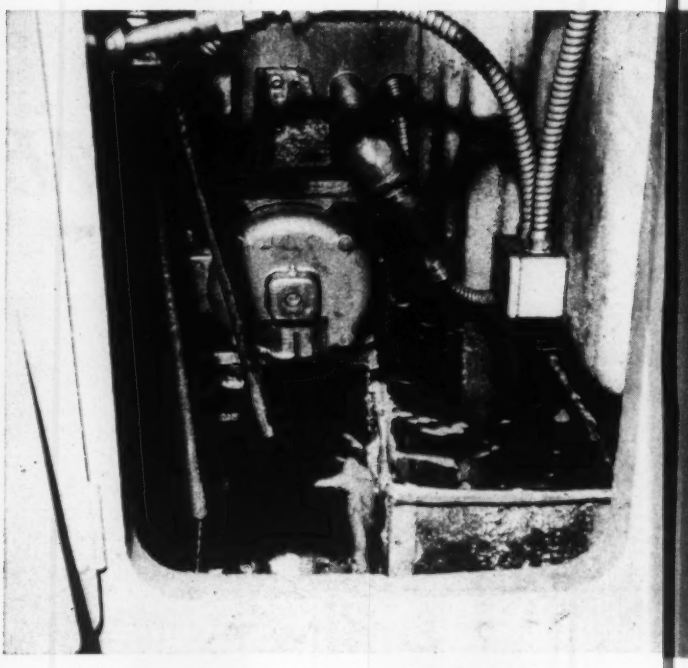


Fig. 2 — Improperly placed coolant discharge on this machine caused fouling of the motor which was almost inaccessible

In another make of motor no means were provided for assuring positive alignment of the bearings after parts had been replaced and the motor reassembled. Only by redesign and reconstruction of the bearing housing and cartridge assembly was the user able to secure correct alignment and eliminate seizing and scoring of shaft or housing on two 75 hp motors which otherwise would have had to be scrapped. In designing for economy of parts replacement these factors must be kept in mind: (1) Ease, (2) simplicity, (3) accessibility, and (4) interchangeability and standardization.

Standardization and interchangeability are, of course, well recognized as the key to our national success in mass production. Nevertheless, designers are still failing in many cases to make full use of these powerful tools. One manufacturer reports excessive maintenance trouble on reciprocating pumps with disk valve failures. The valve stems are available in a great variety of diameters and threads. This results in high parts inventory and causes confusion and delay on the part of mechanics who must determine and select the proper type to install.

Effective, safe, and easy means of lubrication is another prime prerequisite of good design. Every designer understands the necessity for adequate lubrication where relative motion between contacting surfaces is involved. However, anyone may readily overlook the fact that when a lubricant must be manually applied or renewed periodically the human element is introduced to complicate the mechanical problems involved. Here the factors of accessibility, visibility, ease of application and safety hazard take over to govern the course of events which so often lead to se-

CASE STUDY NO. 2

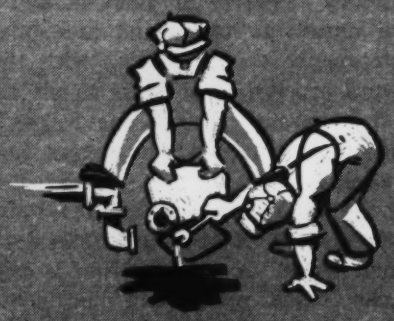
Excessive maintenance labor caused by designer's failure to consider maintenance methods and requirements.

Equipment:
Two hundred vacuum pumps.

Maintenance Problem:
To remove crankcase drain plug located on bottom of machine base for required frequent oil changes requires two men to disconnect, dismount and raise each machine over a drain pan. Average weight of machines, 100 lb.

Makeshift Solution:
Pumps are being remounted on stands to provide access to drain plugs.

Proper Original Design Suggested:
Pipe the drain out of side of pump instead of bottom.



CASE STUDY NO. 3

High salvage and modification costs caused by designer's failure to consider consequences of wear failure.

Equipment:
Gear pumps.

Nature of Problem:
Gears and shafts are integral, necessitating scrapping of good gear when shaft is worn beyond repair.

Salvage Method Used:
Remove worn shaft from gear, bore gear and fit to shop fabricated shaft.

Proper Original Design:
Provide gears that are removable from worn shafts.

rious repairs with attendant down time.

These same factors play a part in complicating the problems of *adjusting, cleaning,* and *painting,* making them unduly expensive operations and discouraging workers from doing them well. *Fig.* 2 shows a coolant line discharging immediately next to a drive motor. The resulting splashing occasionally fouls the motor, which as is shown, is mounted with the drive end almost inaccessible. Then, of course, there are the other flagrant design violations, like the offset cored oil passage which became clogged and could be cleaned out only by drilling a new access passage in the casting to reach the obstruction. These seem ridiculously easy to avoid but, nevertheless, recur continuously to the embarrassment of designers and the detriment of maintenance budgets.

The element of *safety* deserves special emphasis in this study because maintenance employees are more likely to have accidents than are production operators. Their work involves a variety of serious hazards. Furthermore, the variety of the jobs assigned to them prevents them from developing safe work habits in handling all of these jobs. Consequently guards are even more important to protect maintenance staff from injury than they are to help the repetitive production worker who learns to avoid the familiar moving parts by force of habit. Brake and shear treadle guards are important, as an example of another hazard, for during a repair operation a heavy part might fall on the treadle and actuate the blade accidentally while the mechanic's hands are in a danger zone.

Breakdowns and *failures to function as required* cause the bulk of maintenance expense and as often as not can be attributed to faulty design in one sense or another. Breakdowns and malfunctioning, it is true, may often be caused by elements beyond the control of the designer. However, if the designer were to give full and proper consideration to all of the factors which it is in his power to control, the maintenance costs of industry would drop materially. It is regrettable that management so often restricts design costs when an additional expenditure for design time would yield nice returns in reduced maintenance cost and increased productivity.

The *failure of parts* to perform properly because of fracture, distortion, wear, vibration, etc., naturally is a prime concern of the designer. The compressor valve strips which failed to seal properly against the valve seat because the pressure applied distorted them beyond the elastic limit may have been acting under conditions which could not have been anticipated by the designer. The hydraulic oil-pump coupling pins which sheared off repeatedly may have been overloaded well beyond the designer's justified expectations.

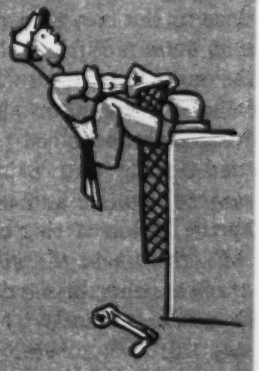
Such cases often occur and perhaps the designer is entirely free of blame. Nevertheless, there are countless examples to be cited indicating real negligence, lack of understanding of operating conditions and evident lack of interest in understanding by the designer with serious results. *Fig.* 3 illustrates just such a case in which the designer ignored the inescapable consequences of wear. He supported a vertical agitator shaft by means of a one piece cast-iron bearing lined with a micarta sleeve and supported by legs welded to the bottom of the agitator tank. As the sleeve wore, replacement could be accomplished only by cutting the supporting legs and dropping the bearing off the end of the shaft. Since wear took place on the shaft also the bearing had to be mounted higher each time on longer legs. To correct this condition the bearing was replaced finally by a split sleeve and the shaft fitted with a hard steel sleeve.

CASE STUDY NO. 4

Faulty design causes down time many times greater than time required for maintenance operation.

Equipment:
Sand blast.

Maintenance Problem:
Each time a crank is applied to perform a manual dumping operation a belt guard must first be removed and then replaced to enable crank to be applied to the shaft.



Proper Design Suggested
Extend shaft through belt guard where it may be reached by crank with guard in place.

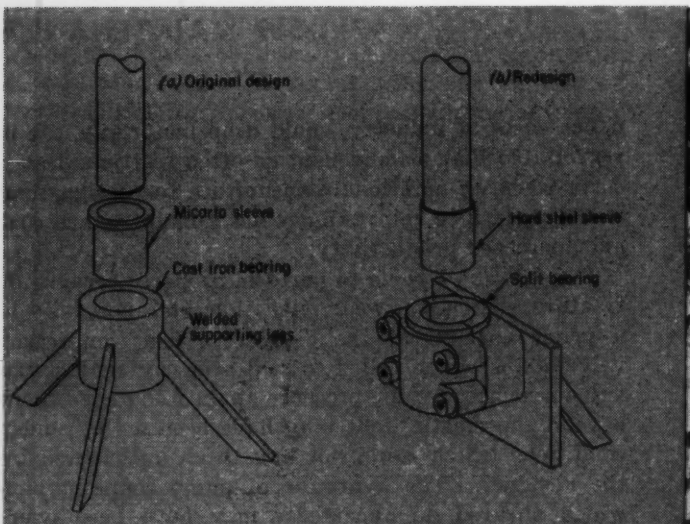


Fig. 3—Redesign of this bearing and support permitted simple replacement after a normal service life

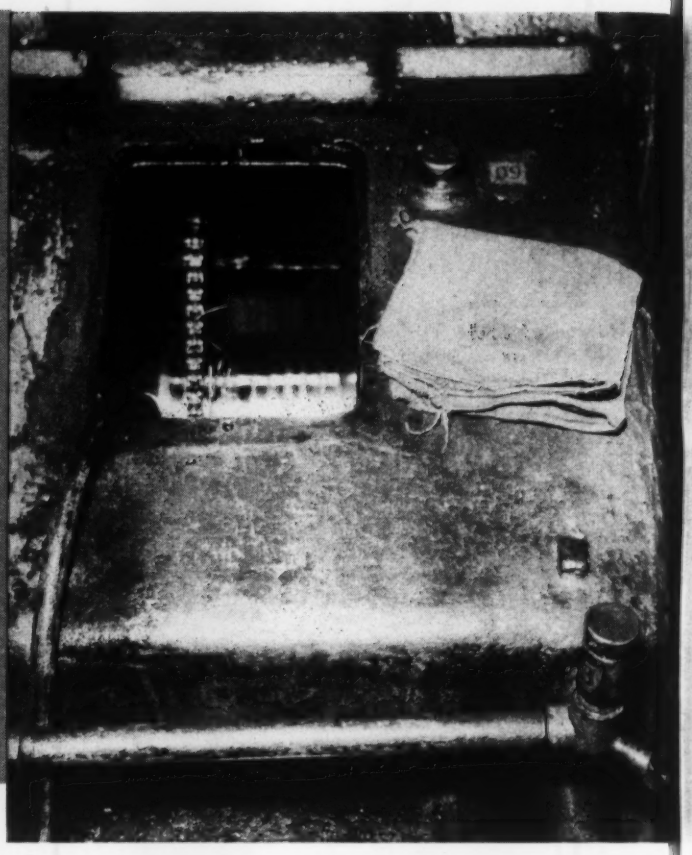


Fig. 4—Machine drive access door such as on this grinder for adjustment of chain and replacement of V-belts require careful consideration to assure adequate working room

Maintenance time was reduced thereby from 32 to 6 man-hours and the life of the unit between replacements was increased from three months to two years.

Examples similar to the foregoing can be found illustrating failure to consider *vibrations, rigidity, cooling,* and the many other physical, chemical, and thermal fundamentals of design. (See Case Studies 1 and 5). These constitute indictments which designers cannot escape since they alone have the knowledge and the tools with which to control the application of these fundamentals.

Similarly, the designer must provide for *positive adjustments* that will not slip and change during operation; *good bearings* that will support their loads without undue wear or heating; and protection of parts, product and operator against harmful *environmental factors.* The maintenance budget was unnecessarily taxed by the designer who placed the drive motor so close to the blower used to compress acid vapors in an acid manufacturing plant that leaking fumes entered the motor and corroded its bearings to the point of failure. A similar charge can be made against the designer who placed pumps and motors inside an air-conditioning unit using lithium chloride, for in this case the pumps and motors were completely corroded by the action of this chemical.

Protection in the event of breakdown or other failure is another prime consideration which must be kept in mind constantly by designers. When babbitt bearings fail in a turbine the babbitt is displaced, the rotor drops and in doing so damages the accurately placed seals. One plant engineer solved this problem in a very economical way by substituting bronze for the babbitt. This type of failure and its consequences are typical. In many cases of breakdown the secondary effects on equipment, product, and personnel are much more costly than the failure itself. Hence, every designer must ask, *"What are the consequences of failure?,"* before being satisfied with any design. This question is particularly important where human beings are involved, especially when exposed to potential hazard.

How Can Minimum-Maintenance Design Be Assured?: If an individual designer applies all of the

CASE STUDY NO. 5

Excessive maintenance caused by design-failure to provide adequate stiffness.

Equipment:
100 hp chain-driven paper machine.

Maintenance Problem:
Frequent bearing replacements (high down time) are required as a result of failures caused by shaft deflections of as much as 0.135-inch under high starting torque.

Proper Design:
Provide sufficient stiffness to withstand the heavy starting load.

various points suggested in the foregoing to a particular design he still might fall short of achieving a "maintenance-free" design. No designer can acquire all of the necessary knowledge concerning maintenance factors by his own individual efforts. He must have the encouragement and the support of his management. He must understand maintenance problems relative to the equipment which he is designing and he has no way of fully acquiring such an understanding unless his management co-operates in a number of ways to help him to gain it.

Management's first step in the direction of developing a maintenance-minded engineering department is to *be sure that its designers understand maintenance problems and procedures* through:

1. Representation in plant maintenance meetings.
2. Shop visits by designers to study actual operating conditions for equipment to be designed.
3. Shop visits by designers to follow up performance of equipment already designed, built and installed.
4. Reading of maintenance literature made available by management.
5. Copies of maintenance cost reports and analyses on equipment previously designed.
6. Reports of all modifications and change suggestions made by shop mechanics or customers.

Representation of designers in maintenance meetings and shop visits by designers are costly in man-hours but may constitute a wise investment in greatly reduced maintenance expense. Representation on maintenance brings to the design department a forceful meassage of the importance of maintenance considerations. The designer who has never seen in the plant the result of his own efforts embodied in its final three-dimensional form—a moving, producing device operated by a living being—has difficulty appreciating the factors of force, space, time, and human interest involved.

No designer possessing this appreciation would have made the simple but costly error of allowing insufficient clearance for removal of the packing gland of a certain pump and of requiring complete disassembly of the pump for repacking. No designer with this appreciation would have designed the motor, which was reported by one maintenance engineer, in which the cooling fan enclosure had to be removed, exposing the moving blades, to permit grease to be drained during a simple lubricating procedure. In one plant periodic shop visits by designers convinced the latter, before serious damage was done, that an oil well concealed within a machine case was collecting dirt which was obstructing the oil lines. They convinced themselves that the theoretical protection offered by the case was of no practical value because of certain unsuspected dirt-laden air currents induced by the moving parts and replaced the sleeve bearings with "oilless" bushings before maintenance costs rose.

Maintenance literature in the form of periodicals, handbooks, equipment manuals, conference reports, etc., is just as important in the design room as design literature is. Sufficient copies should be provided to allow the staff to withdraw issues for home reading. However, the management should encourage a reasonable amount of such study on the job if real interest and results are to be expected. *Maintenance cost reports* likewise should be furnished to the design department covering all equipment designed whether for plant or consumer use. *Reports of modifications and suggestions by shop mechanics or by customers* should likewise be provided for the design department. All such reports give the designers background data for improving all future designs and avoiding past design errors.

These reports are particularly effective also in impressing designers with the costliness of maintenance errors on their part. In the case of a special press a user's suggestion of substituting sealed needle bearings for bronze sleeve bearings, which were failing because of contamination, was readily adopted by the alert manufacturer with the result that the new machines installed are showing a saving of $300 per year per machine to his customers. In another case involving a special automatic machine, a report of a mechanic's suggestion reached the design department with the result that a design modification in a glass stopcock reduced maintenance costs by $600 per year per machine and insured better quality control of the product. Reduced maintenance must be the joint objective of all parties involved including management, designers, operators, maintenance men, field men, etc.

The second major step in insuring maintenance-free designs is to *correlate all maintenance data for easy*

CASE STUDY NO. 6

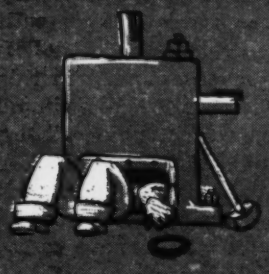
The designer's lack of understanding of operating conditions resulted in excessive maintenance.

Equipment:

Mechanical seal on agitator shaft.

Maintenance Problem:

The improperly selected mechanical seal was rendered inactive by the action of the materials being agitated and required replacement at least once a month with an average of seventy-five man - hours of maintenance labor.



Solution:

Mechanical seal was replaced by a split-ring packing gland which requires only two man-hours to replace and lasts two or three months because of the improved properties of the packing material selected.

Proper Design Procedure Suggested:

Study operating conditions thoroughly before selecting shaft seals or other machine parts.

reference, standardize maintenance factors and incorporate them with the company's design standards. Fig. 4 shows the access door to an old-style grinder through which V-belt replacements and all drive adjustments must be made. Proper working standards for such openings can be determined readily in co-operation with the maintenance department and included in the manual of design standards. Maintenance design standards are as important as standards for strength, function and life, yet how seldom are they really considered!

Have designs checked by a maintenance representative. This next step in the system for insuring sound design is almost obvious in its reasonableness, yet few companies are concerned about bringing the maintenance department into the design process until the equipment is in operation, failures occur and redesign is in order. In *Fig.* 5 is shown a clean-out door that had to be cut in the base of a hobbing machine by the maintenance shop in order to clean out the chips. The designer originally had made provision for a clean-cut opening but had baffled the base in such a manner that few of the chips could be reached. It is practically certain that a maintenance representative would have spotted this difficulty while the design was on the board but no such person was consulted at that stage of the development.

Fig. 5—Floor-level cleanout door for chip removal was necessary on this machine to permit accessibility

The final step, which is probably the most important in the process of insuring sound design, is to *help designers to understand the operation of all equipment being designed.* This is a difficult principle to put into effect fully because one rarely gains a thorough understanding of any operation through vicarious experience—and no designer can personally operate all the types of equipment that he is required to design, and certainly not when he is designing something new. Nevertheless, by participating in the steps previously mentioned he can gain a background of familiarity which will enable him to predict operating characteristics of common machines and the machine elements of which all equipment is composed.

A designer who was not familiar with the performance of common machine elements — or just wasn't concerned—designed a gearbox to be kept two thirds full of oil. At 1400 rpm centrifugal force caused the exposed gear teeth to throw the oil outside the case until the bearings failed, dropping their balls into the gear teeth, destroying the gears and springing the case. The rebuilt unit is maintained full of oil so that the gears run completely submerged and without further trouble. Preventive maintenance in this instance should have started on the design board with a better understanding of machinery by the designer.

Maintenance reduction is one of industry's most pressing problems today with manpower becoming more scarce and competition for sales becoming more keen. Millions of dollars and untold manpower can be saved annually in this country if maintenance can be minimized and simplified. The foregoing suggestions point up the strong role that designers can and should play in accomplishing this dual objective. With the support of management they can do more than any other single group in industry to guarantee minimum maintenance costs on machines and production equipment.

CASE STUDY NO. 7

Poor design resulted in a serious safety hazard to maintenance staff.

Equipment:
Gas-engine driven centrifugal pump for cleaning out pits.

Safety Hazard:
Poorly designed hand-crank mechanism on gas engine failed to disengage and broke the maintenance man's wrist.

Remedy:
All portable equipment has been equipped with self starters.

ACKNOWLEDGEMENT

The author gratefully acknowledges the contributions of the following organizations to this study generously furnished in the form of data, illustrations and counsel:

American Cyanamid Co., Lederle Laboratories Div. ..... Pearl River, N. Y.
American Mutual Liability Insurance Co. ... Boston, Mass.
Atlantic Refining Co. ..... Philadelphia, Pa.
Caterpillar Tractor Co. ..... Peoria, Ill.
Deere and Co. ..... Moline, Ill.
Delco-Remy Div., General Motors Corp. ... Anderson, Ind
Eastman Kodak Co. ..... Rochester, N. Y.
Eli Lilly and Co. ..... Indianapolis, Ind.
Ocean Accident and Guarantee Corp. Ltd. .. New York City
Republic Steel Corp. ..... Cleveland, O.

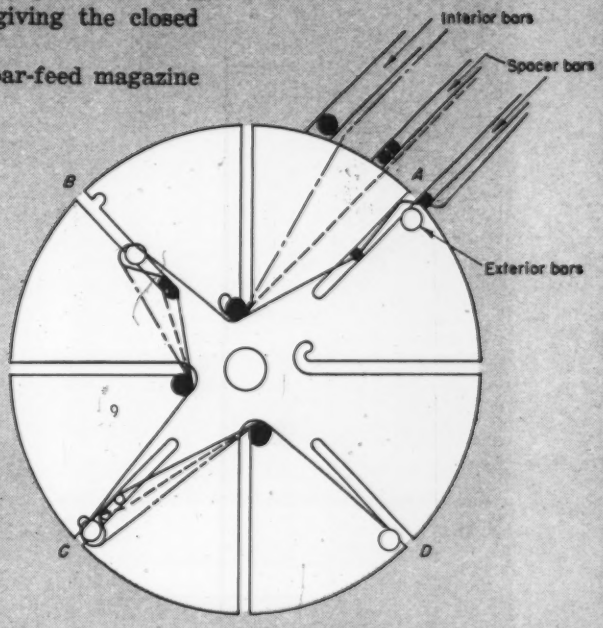
SCANNING the Field for IDEAS

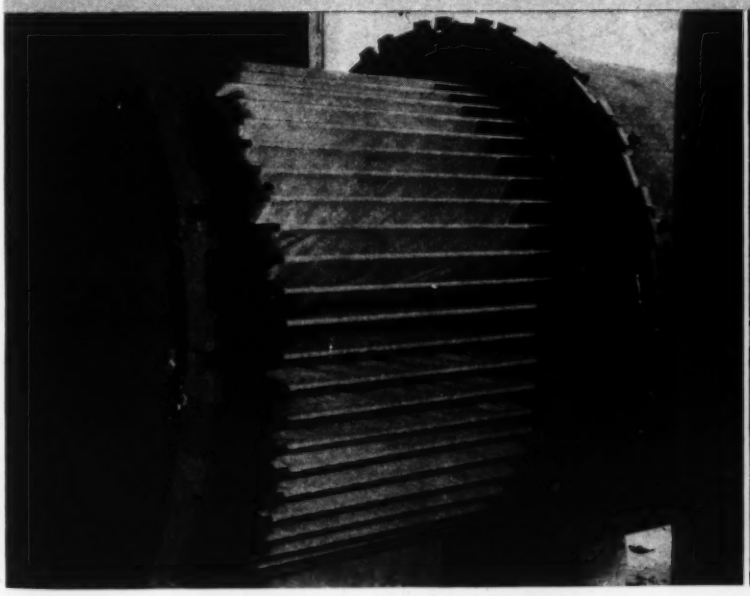
CONTINUOUS ADVANCE of fabric wraps on the rotor of a new pressure dyeing machine enables all portions of the fabric to have equal contact with the dyeing liquor. Designed by Paul M. Cole of the DuPont machine development section, the Barotor dyer fits in an autoclave with the drive shaft passing through the head. As the rotor turns counterclockwise, gravity causes bars between wraps of the fabric to move in and out radially, giving the closed loops of fabric a forward motion relative to the rotor.

To load, fabric ends are brought through spaces in the bar-feed magazine and temporarily attached to one exterior bar, *D*. As each wrap is fed in, a spacer bar, *A*, drops into its slot, thus placing a spacer bar between each fabric wrap. Interior bars also drop into J-shaped slots on top of all wraps. After all slots have been loaded (one revolution of the rotor) the original lead-in end of each wrap is unfastened and sewed to the tail end.

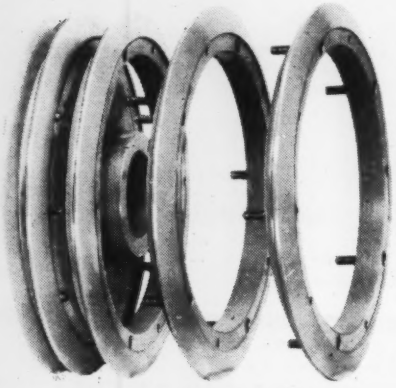
When the rotor reaches a position approximately 60 degrees from the horizontal as at point, *B*, an exterior bar rolls toward the center. At the same time, a set of exterior and spacer bars is passing the horizontal and rolls to the outside end of the slot as shown at *C*, to take up the slack let out by the exterior bar, and the fabric progresses forward. Progressing action continues as long as the rotor is turned.

After the batch dyeing cycle is complete, the bar-feeding magazine is moved below the horizontal. Sewed fabric ends are cut and threaded back through the magazine, after which the rotor is turned clockwise for rewinding, automatically returning all bars to the magazine.

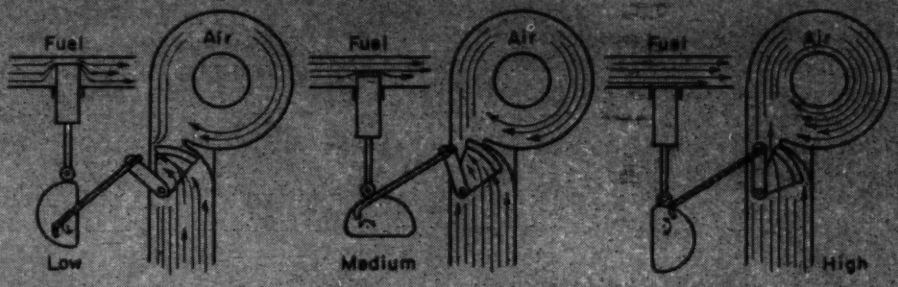




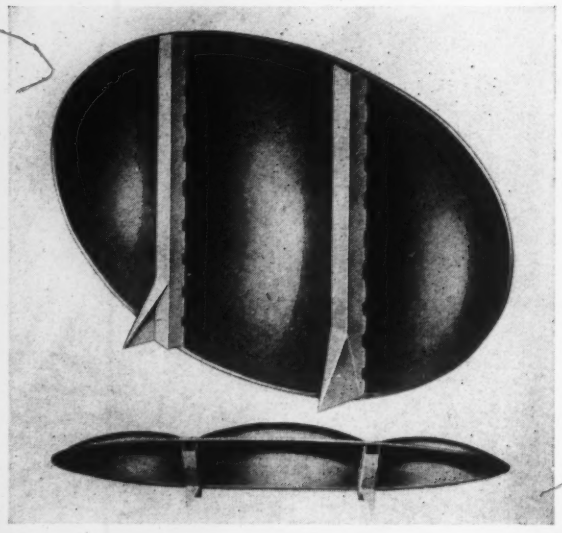
Ideas



EXTENDABLE-GROOVE SHEAVES simplify matching horsepower requirements in V-belt drives. Barclay "add-a-ring" pulleys for A through E-section belts are designed so that the exact number of rings necessary for multiple-belt drive can be assembled on a plain or taper-hub spider. To add grooves, interchangeable rings are bolted on with socket cap screws to either side of the sheave to place the hub in desired position. Pitch diameters range from 3.4 to 28 inches.



DEMAND CONTROL of fuel and air proportions to the burner of Orr and Sembower boilers provides uniformly high efficiency across the operating range. An adjustable cam and linkage mechanism positions the air-fuel valves in accordance with steam demand through a pressure-controlled potentiometer in the damper motor circuit. Efficiency is maintained down to 30 per cent full load by furetest setting of the mechanism against actual flue gas analyses.



TRIPLE-DISHED FLANGED BULKHEAD design developed by the Heil Co. is said to result in vastly superior strength over conventional types. Three deeply dished contours are separated by two full height straight surfaces to which box-section reinforcing channels are welded. Stress analysis and strain gage tests show improved resistance to liquid surge and increased efficiency in transfer of shear loads.

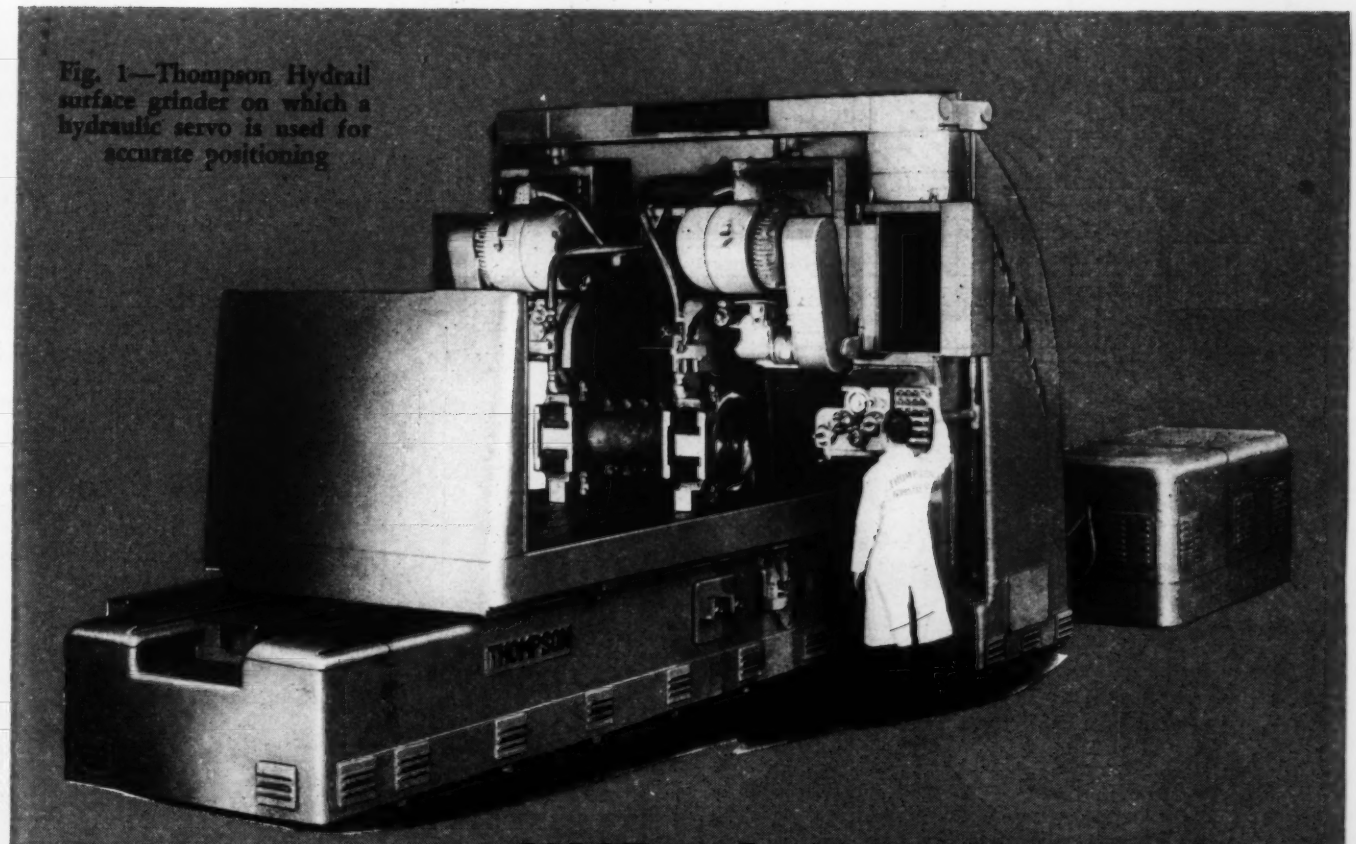


Fig. 1—Thompson Hydrail surface grinder on which a hydraulic servo is used for accurate positioning

HYDRAULIC SERVO

. . . . redesigned for accuracy and stability through research and model analysis

By Walter Ernst
Vice President, Director of Engineering
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Dayton, Ohio

IN THE DESIGN of highly specialized equipment, a manufacturer often finds that his final prototype exhibits undesirable characteristics for which no ready remedy seems to be available. Not wishing to drop the months of labor and money spent on the design, he will sometimes turn to outside sources to correct the trouble. Such a problem, undertaken by this organization, involved a servomechanism that was acting erratically. Inasmuch as the solution of the problem involved several new points, it should be of interest for similar cases.

Servo Problem: For a surface grinder, *Fig.* 1, the servo was designed to operate the table for accurate positioning, under manual control, both in the set-up or make-ready period and in certain grinding operations. The device was of the rotational type and ingeniously designed to perform its intended functions. However, demands of customers required greater accuracy in positioning the table. Three major objections were reported: poor response to small displacements, large transient error, and jerky movement of the load. The problem was to overcome these faults and then subject a new model to tests for response transient error, steady-state error, and stability.

The valve-controlled servomotor was designed to move the table in translational movements of infinite length in response to an infinite signal movement. Advantages and disadvantages of several alternate types, all fully proved, were carefully considered.

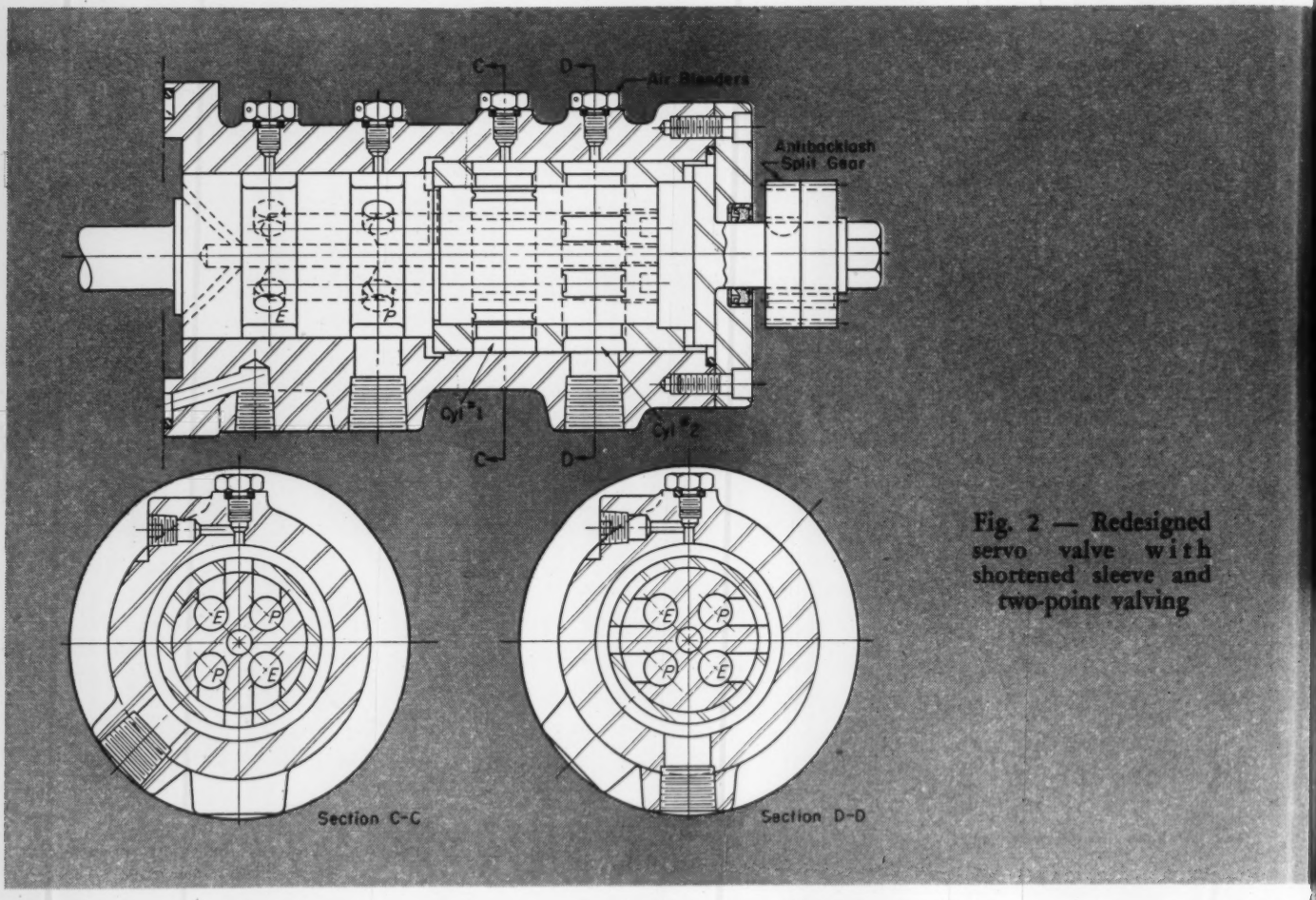

Fig. 2 — Redesigned servo valve with shortened sleeve and two-point valving

However, it was decided to use the original model and concentrate on design improvements.

Analysis showed that higher differential pressures would be needed to operate the servomotor than those required for movement of the grinder table. As a general proposition, it was assumed that pressures 100 per cent above those required for the machine would be needed for the servomotor. Also, it was desired to hold velocities in the pipe lines to the lowest possible value. To reduce fluid friction losses and leave the highest possible pressure for acceleration and throttling loss through the control passages. The longer these lines, the greater the losses; therefore, it seemed desirable to increase the size where longer transmission lines are required and decrease on short lines. The new unit that was designed accommodates a flow of 5 gpm of oil at 150 SSU viscosity at 100 F.

Valve Design: Originally, the servo sleeve ran the full length of the servo plunger. Because intake and exhaust openings need not and should not go through the sleeve, it was shortened to cover only the two motor connections, *Fig.* 2. The plunger was stepped with its large diameter fitting the body and smaller one fitting the sleeve. The shorter sleeve is easier to grind without taper and can be more closely fitted.

In the original design, six passages with three points of valving in each plane were provided. This was changed to four passages with two points of valving, 180 degrees apart and by this means manufacturing cost was reduced. Parts were made with negative lap to eliminate "dead spots" caused by positive lap on the sleeve slots in neutral position and the need for accelerating the stationary fluid column. The sleeve and feedback shaft were made in one piece which was feasible with the new short sleeve design, *Fig.* 2. To make it applicable for a greater variety of uses, all of the internal drains were brought together in a drain connection which would be piped to the reservoir, eliminating other drains. Air bleed plugs to stop jerky movement were provided at the highest point in all passages. The feedback gear was given a backlash adjustment.

Test Results: With calculations, layout, and shop drawings for the improved mechanism completed, attention was directed to preparing a testing mock-up. The mock-up consisted of a bedplate with ways to carry a cast-iron slide weight, *Fig.* 3, which would be reciprocated by a hydraulic cylinder. A rack, attached to the slide weight and guided in a way alongside the cylinder, reciprocated with the weight. The servo valve unit was mounted on the base as shown in *Fig.* 4 with the split gear at the servo output engaging the rack adjusted for elimination of backlash. By supplying hydraulic power to the servo unit and cylinder, it was possible to conduct the tests.

Tests involved operation of the mechanism under simulated production conditions. These tests did not show all the desired results. A lack of response to small valve displacements was noted. The reasons were found to be backlash in the planetary gearing,

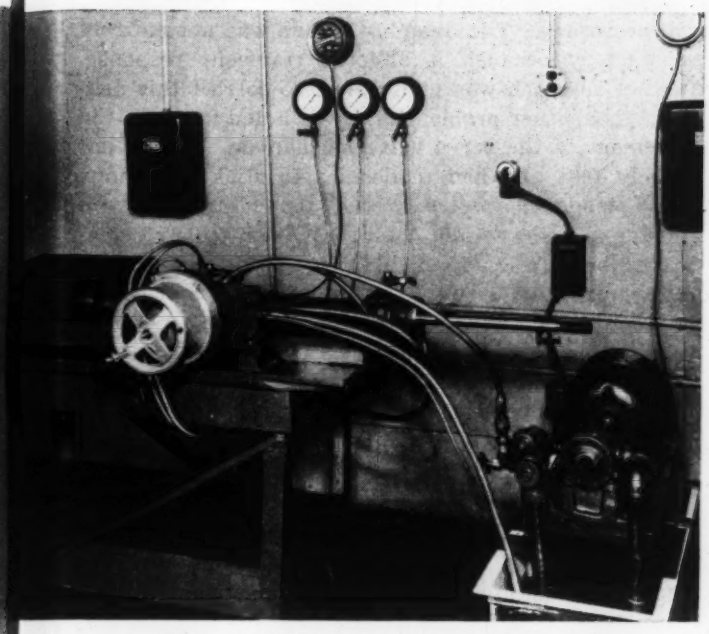

Fig. 3—Mock-up arrangement for testing the characteristics of the redesigned servo

inaccuracies in the servo valve sleeve, defects in the test equipment, and erratic behavior of oil flow in narrow clearance spaces. The first three causes were easily remedied but the fourth involved extended experimental and analytical investigation that resulted in a new theory of fluid behavior.

In very narrow passages the flow of fluid was found to be erratic and not subject to any law. As the passages exceeded a certain minimum width, the flow became turbulent and followed the square-root law. At least 0.001-inch clearance, and preferably more, was required to establish stable flow conditions. Then the flow through the passages became proportional to the square roots of pressures, indicating turbulent flow.

Based upon these test results, a theory of pressure distribution in the unit was developed. It was found that the pressure differential, established upon slight movement of the servo valve, equals the quotient of the difference and the sum of the squares of the clearances existing on both sides of one of the valve heads.

In neutral position of the valve all clearances are the same (by design). If we denote these neutral clearances as c, the change in clearance due to valve movement as Δc, system pressure as P_0, and $P_1 - P_2$ as the difference in pressure at the ends of the power piston, then

$$\frac{P_1 - P_2}{P_0} = \frac{(c + \Delta c)^2 - (c - \Delta c)^2}{(c + \Delta c)^2 + (c - \Delta c)^2}$$

or

$$\frac{P_1 - P_2}{P_0} = \frac{4\,c\,\Delta c}{2(c^2 + \Delta c^2)}$$

For small displacements, Δc^2 may be neglected and we have

$$\frac{P_1 - P_2}{P_0} = \frac{2\,\Delta c}{c}$$

This simple relationship enables a quick computation of the expected response to small valve movements. For instance, if the neutral clearance c equals 0.001-inch and the displacement Δc equals 0.0002-inch, then the pressure difference available to move the servo motor will be 40 per cent of the impressed pressure. In this simple and effective manner a modulating type of servomechanism may be constructed. It can be developed for any desired response accuracy within physical limits of obtainable flow.

Further calculations showed that, with increasing slot width, the leakage loss increased rapidly. When

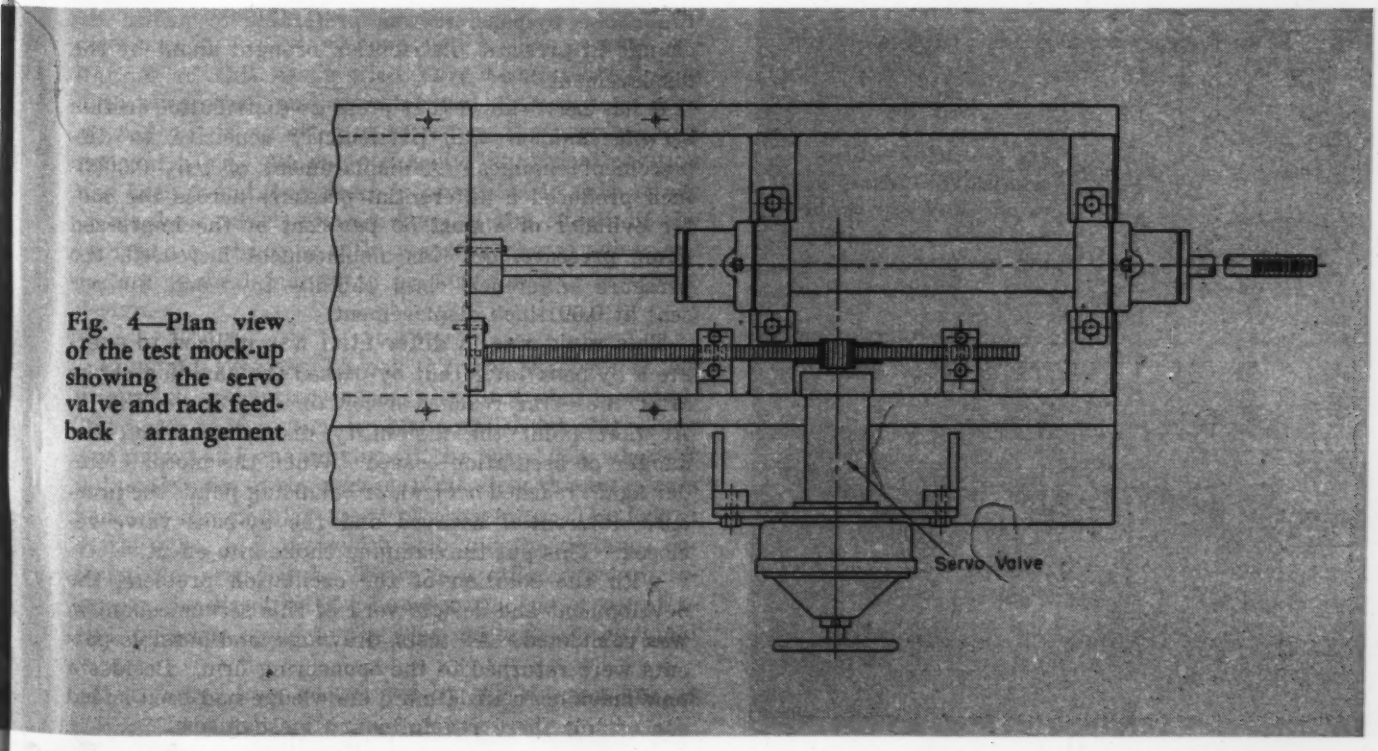

Fig. 4—Plan view of the test mock-up showing the servo valve and rack feedback arrangement

employing a constant delivery pump as power source, this condition is not too serious as long as the available capacity of the pump is not exceeded. It is more or less immaterial whether the output is wasted through the passages in the servo unit or through a relief valve. With an accumulator or variable delivery pump system such leakage loss is definitely objectionable and should be reduced to the minimum. The best compromise between response, stability and minimum leakage loss appears to be about 0.002-inch slot width. This was used as the basis for succeeding tests.

With the unit remachined to the 0.002-inch slot width, tests were again made. The slot opening was satisfactory but a new problem of oscillation became apparent. Driving pressure was put at sufficient magnitude to obtain the required accuracy with small table displacements and to permit the table to zero-in. When this pressure exceeded the threshold pressure, violent oscillation of the table resulted. As used in this particular problem, threshold pressure was the minimum pressure required to move the table. The oscillation was stopped by means of choke valves interposed in the cylinder or outlet lines from the servo. It was found that this expedient tended to lower the threshold pressure and a compromise was possible between response accuracy and transient response.

At this stage, it was felt that optimum results were still necessary. The damping means was not entirely satisfactory because it affected transient response. Further research was undertaken to correct this deficiency. Another problem that was noted involved the movement of the servo valve mechanism. It was not entirely free and had tendencies to stick and jump. These tendencies were traced to locking between plunger and sleeve and could be eliminated by remachining or redesign of the unit.

Delving into the problem further, tests continually pointed to micronic dirt particles in the oil as the cause of erratic oil behavior in small capillary passages. These impurities tended to plug or "plate over" the fine openings of the unit and the flow ceased.

Installation of proper filtering apparatus greatly reduced the irregularity. This influence of micronic dirt is not too detrimental in the larger openings possible in the modulating type of servomechanism. The exception to this may be in a machine operated for long periods and under severe conditions where the oil has deteriorated far more than that used in the test setup. However, if greater response accuracy is required for accurate contour tracing or foolproof operation over long periods of time, the installation of properly engineered filtration equipment would appear to be desirable and necessary.

Final Solution: Oscillation could be damped by installing a choke valve in one of the lines leading from the servo valve to the servo cylinder, *Fig.* 5, and when attempting to operate the servomechanism at high speeds and/or large displacements, this velocity responsive choke came into action. The result was an undesirable increase in transient error. An obvious expedient was to use this "error" to operate a means to by-pass the velocity responsive choke and thus bring about a reduction of itself.

The error manifested itself by a displacement lag between servo valve and servo sleeve. Rather than use this displacement lag as an operating device for the choke by-pass, it was preferable to utilize the change in pressure distribution brought about by the displacement.

It has been shown that pressure distribution in this servomechanism was particularly sensitive to displacement changes. A displacement of only 0.0005-inch produced a differential pressure across the motor cylinder of almost 50 per cent of the impressed pump pressure. As this displacement increased, the pressure difference rises rapidly to reach 80 per cent at 0.001-inch displacement.

This rapid rise in differential was utilized to operate a by-pass valve that by-passed the damping choke after the error reached a certain magnitude, *Fig.* 6. At that point the instability disappeared and the danger of oscillation ceased. When the motor cylinder again reached neutral, or balancing point, the pressure differential decayed and the by-pass valve reclosed. This put the damping choke into effect.

With the solution of the oscillation problem, the development and design work of this servomechanism was completed. All tests, drawings, and possible patents were returned to the sponsoring firm. Besides a new machine, a little more knowledge had been added concerning these revolutionary mechanisms.

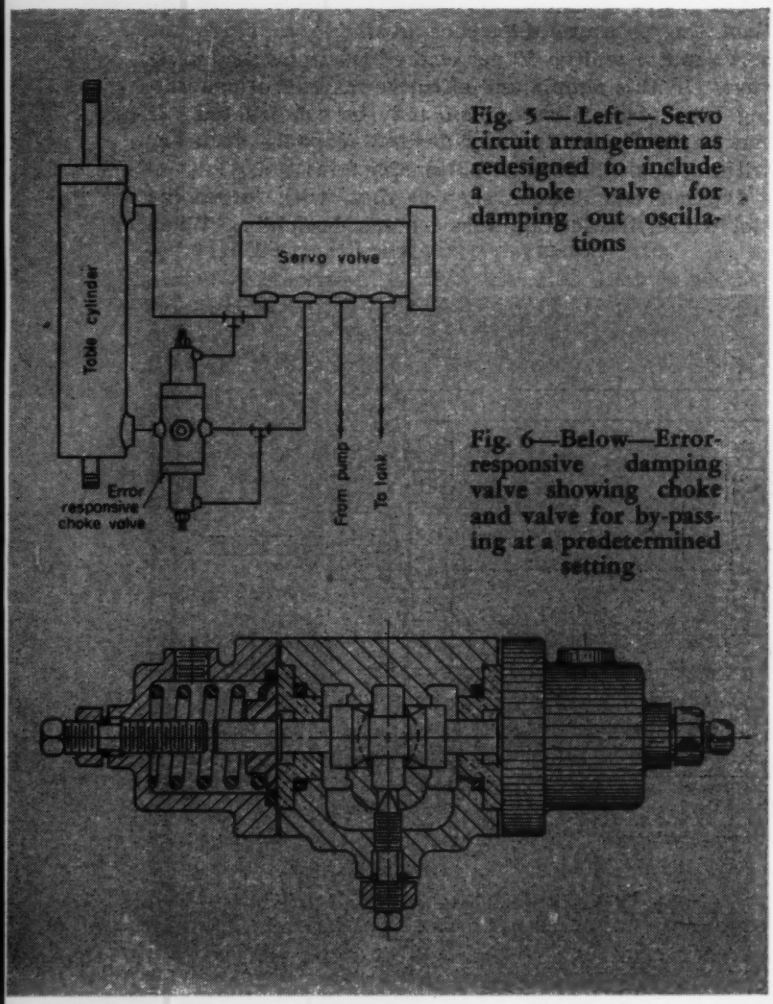

Fig. 5 — Left — Servo circuit arrangement as redesigned to include a choke valve for damping out oscillations

Fig. 6—Below—Error-responsive damping valve showing choke and valve for by-passing at a predetermined setting

By Warren E. Wilson
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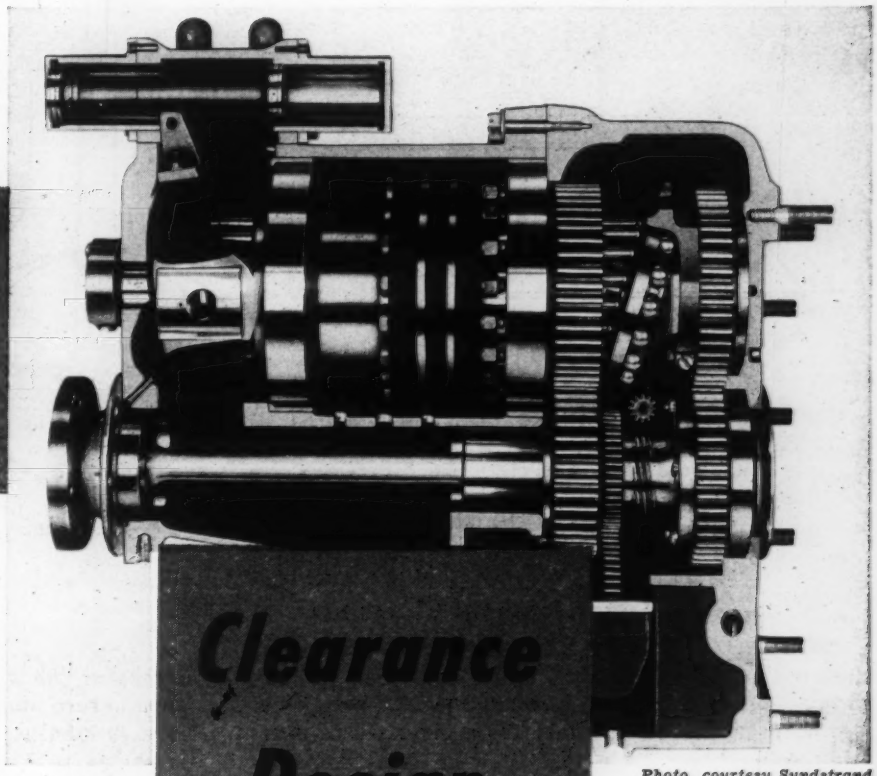
Rapid City, S. D.



Photo, courtesy Sundstrand Machine Tool Co.

Clearance Design

. . . in positive-displacement pumps

DESIGN of clearances in positive-displacement pumps and motors, based upon the assumption of constant viscosity of the liquid, has been discussed in earlier publications.[1, 2] The serious limitations of this assumption have been realized, and both theoretical and experimental studies have been carried out in an attempt to reduce the problem to a rational basis. No comprehensive analytical solution has been found, but there is presented in this article an analysis which reveals some of the effects of the variation of viscosity with temperature and points out certain general factors to be considered in clearance design.

Constant Viscosity Theory: For the purposes of this discussion a clearance passage is illustrated in *Fig.* 1. The passage is formed by two parallel flat plates, one stationary and one moving at the speed $R\omega$, where R is the distance of the moving plate from the pump axis and ω is the angular speed of the pump. The length of the plate is l, the width is b and the distance between the plates is h. There is a difference in pressure in the direction of l, between one end of the plate and the other, equal to Δp. The viscosity of the liquid is μ.

The power loss, occasioned by the slip passage, is the sum of the power loss due to slip, $Q_s(\Delta p)$, where Q_s is the rate of slip flow and the power loss due to viscous drag. The expression for this power loss, when the viscosity is a constant μ_0, is

$$P_L = \frac{(\Delta p)^2 b h^3}{12 \mu_0 l} + \frac{R^2 \omega^2 \mu_0 l b}{h} \quad \ldots\ldots (1)$$

Writing this expression in terms of the clearance width ratio h/b gives

$$P_L = \frac{(\Delta p)^2 b^4}{12 \mu_0 l} \left(\frac{h}{b}\right)^3 + R^2 \omega^2 \mu_0 l \left(\frac{b}{h}\right) \quad (2)$$

This equation can be rewritten in dimensionless form:

$$\frac{P_L}{\frac{(\Delta p)^2 b^4}{12 \mu_0 l}} = \left(\frac{h}{b}\right)^3 + \frac{12 R^2 \omega^2 \mu_0^2 l^2}{(\Delta p)^2 b^4} \left(\frac{b}{h}\right) \quad (2a)$$

If the power loss is plotted as a function of the clearance ratio h/b, a curve of the form shown in *Fig.* 2 is obtained.

The minimum power loss P_{Lmin} occurs at

$$\frac{h}{b} = \sqrt{\frac{2 R \omega \mu_0 l}{(\Delta p)\, b^2}} \quad \ldots\ldots (3)$$

The assumption of constant viscosity led to the con-

[1]References are tabulated at end of article.

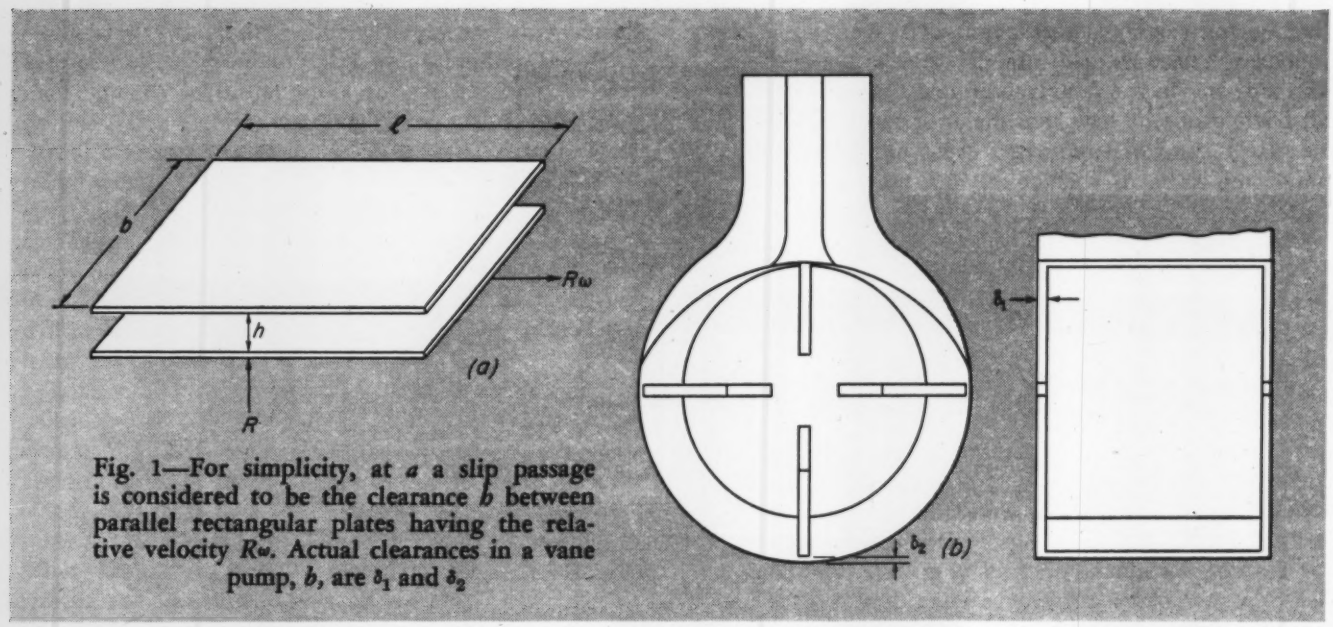


Fig. 1—For simplicity, at *a* a slip passage is considered to be the clearance *b* between parallel rectangular plates having the relative velocity $R\omega$. Actual clearances in a vane pump, *b*, are δ_1 and δ_2

clusion that there is an optimum clearance for any slip passage, and it would give significantly less power loss than any other clearance for a given set of operating conditions. This fact may be interpreted by considering that, if the clearance is very small the viscous drag is very large, and the power loss due to that factor is correspondingly great. On the other hand, if the clearance is large, the slip is excessive and the power loss is again very large. An intermediate value of the clearance would necessarily give a minimum power loss.

Variation of Viscosity: Experiments directed toward determining the variations of viscosity with flow conditions and the corresponding effect on the flow in the case of simple pipe flow have been performed. These experiments investigated the rate of flow of ordinary engine oil in a straight circular pipe with a high pressure differential and revealed that the actual flow was much greater than that predicted by the usual elementary theory involving constant viscosity. Experimental difficulties, however, precluded the possibility of obtaining significant quantitative results in terms of the constants describing the flow. A theoretical discussion of this problem led to the conclusion that very large increases in the rate of flow could be expected and the experiment indicated even greater rates of flow.[3]

In order to illustrate the effect of the variation of clearance on viscosity and on power loss, the following relationship between viscosity and clearance will be assumed:

$$\frac{\mu}{\mu_0} = 1 - \frac{1}{1 + c\frac{h}{b}} \qquad (4)$$

where μ is the average viscosity in the flow passage and the dimensionless coefficient c determines quantitatively the relationship between the viscosity and the clearance. This coefficient will vary directly with the viscosity index (V.I.) of the liquid. Under this assumption the viscosity goes to zero when the clearance is zero and is the initial value μ_0 when the clearance is infinite. The general form of the relationship is shown in *Fig.* 3 for three different liquids. This graph will conform with the actual relationship in a general way, provided all the factors controlling the flow and transfer of heat through the passage walls are constant.

Combining Equation 4 and Equation 2 gives the following expression for power loss:

$$P_L = \frac{(\Delta p)^2 b^4}{12\,\mu_0 l}\left(\frac{h}{b}\right)^2 \frac{1 + c\frac{h}{b}}{c} + \frac{R^2\omega^2 l\,\mu_0 c}{1 + c\frac{h}{b}} \qquad (5)$$

This equation can be rewritten in dimensionless form:

$$\frac{P_L}{\frac{(\Delta p)^2 b^4}{12\,\mu_0 l}} = \left(\frac{h}{b}\right)^2 \frac{1 + c\frac{h}{b}}{c} + \frac{12\,R^2\omega^2\mu_0^2 l^2}{(\Delta p)^2 b^4}\,\frac{c}{1 + c\frac{h}{b}} \qquad (5a)$$

From Equation 5*a* the rate of change of the power loss with respect to the clearance ratio h/b at $h/b = 0$ is

$$\frac{\partial P_L}{\partial\left(\frac{h}{b}\right)} = -\frac{R^2\omega^2 l\,\mu_0 c^2}{\left(1 + c\frac{h}{b}\right)^2} \qquad (6)$$

which is always negative. The value of the power loss P_{L0} at $h/b = 0$ is

$$P_{L0} = R^2\omega^2 l\,\mu_0 c \qquad (7)$$

The following dimensionless quantity appears in both Equations 2*a* and 5*a* and may be represented by K:

$$K = \frac{12\,R^2\omega^2\mu_0^2 l^2}{(\Delta p)^2 b^4} \qquad (8)$$

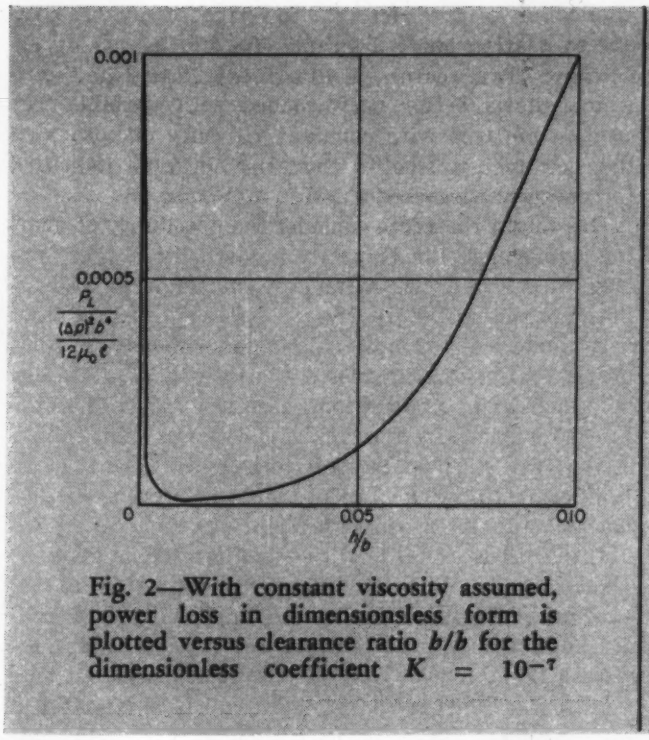


Fig. 2—With constant viscosity assumed, power loss in dimensionless form is plotted versus clearance ratio h/b for the dimensionless coefficient $K = 10^{-7}$

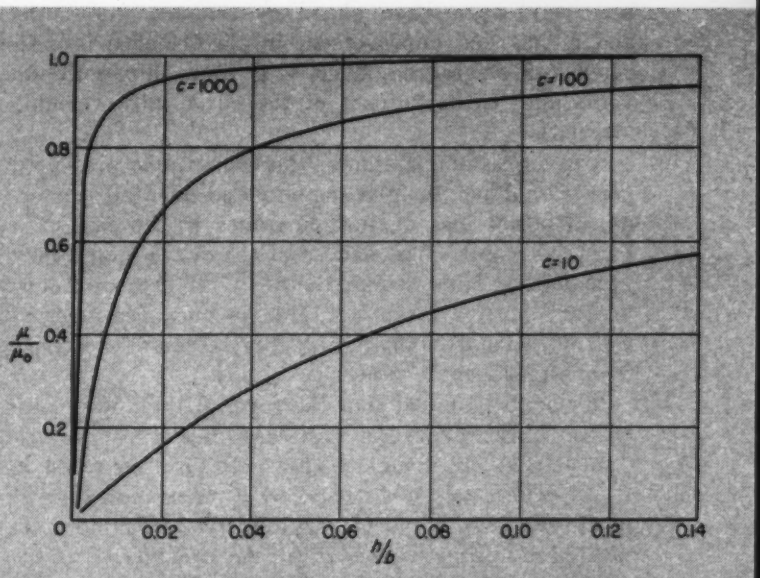


Fig. 3—Relationship between viscosity and clearance is shown for liquids with three different values of the dimensionless coefficient c which varies directly with viscosity index

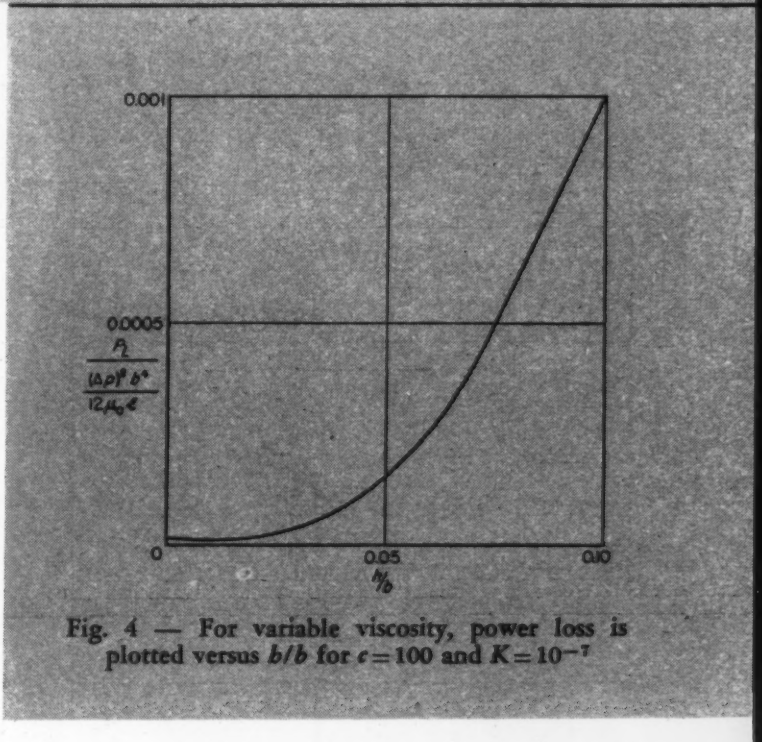


Fig. 4 — For variable viscosity, power loss is plotted versus h/b for $c = 100$ and $K = 10^{-7}$

The quantity K is the product of the dimensionless length ratio R^2l^2/b^4 and the dimensionless hydraulic factor $(\mu_0\omega/p)^2$ and the number 12. It is therefore a dimensionless factor descriptive of the flow conditions and the geometry of the flow passage and has been adopted to simplify the nomenclature of the plottings of equations. The general shape of the curve relating P_L and clearance ratio h/b is shown in *Fig.* 4.

This relationship indicates that even with a liquid of variable viscosity there is an optimum clearance but that the power loss for very small clearances is not very different from that at optimum conditions. This fact is an excellent confirmation of findings in practice that little change in performance can be effected by changing clearance once a reasonably small clearance has been selected.

The reason for this situation may be clarified by consideration of an equation for power loss due to viscous drag which can be developed from Equations 4 and 7. This power loss, P_{Lv}, is

$$P_{Lv} = \frac{R^2 \omega^2 l \mu_0 c}{1 + c\frac{h}{b}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

When h/b is very small the principal power loss is due to viscous drag, P_{Lv}. Under these conditions a change in h/b causes very little change in P_{Lv} since the term $c(h/b)$ would then be very small compared with the quantity 1 to which $c(h/b)$ is added in the denominator of the expression for P_{Lv}.

Applications in Practice: Practical application of this knowledge involves primarily an appreciation of the limitations of the equation for variation of viscosity with clearance and of the many factors involved in the variation of the viscosity in a practical case.

Based on the assumption that the predictions of the theory presented above are qualitatively significant, a comparison between power loss with constant viscosity and with variable viscosity as a function of clearance-width ratio is shown in *Fig.* 5.

Several features of this comparison are significant from the practical standpoint. The crossing of the curves for constant viscosity and those for variable viscosity in the neighborhood of the minimum point of the constant viscosity curve indicates that if the optimum clearance predicted by constant viscosity theory were selected for design purposes a reasonably efficient design would be effected.

This fact is significant in that the clearance predicted by the constant viscosity theory is frequently

relatively large when gaged by ordinary standards, and no marked improvement in performance is indicated for clearances much less than this optimum value due to the flatness of the curve with variable viscosity.

A practical application of the background presented here would be the plotting of experimentally determined power loss against clearance in the case of a pump or motor. The details of the curve might vary considerably from that predicted by the present theory but the general form should be as indicated, permitting a rational evaluation of the optimum clearance from experimental data.

It should be noted that the form of the power loss-clearance ratio curve is markedly affected by the viscosity index of the oil. This point is illustrated in *Fig.* 5 where oils of low viscosity index indicated by small values of c and of very high viscosity index indicated by large values of c are considered in the power equation in comparison with a constant viscosity oil.

A final observation concerns the possible practical application of the fact that lowering of oil viscosity due to heating has a desirable effect in increasing efficiency. This feature is illustrated clearly in *Fig.* 5 which shows better performance with variable viscosity compared with constant viscosity oil, provided the clearance is smaller than the optimum indicated for constant viscosity.

One might therefore consider the possibility of heating pump elements to decrease viscosity if there are large areas of close contact producing large viscous drags on the moving parts.

A numerical example serves to demonstrate some of the outlined principles. Consider a slip passage 0.75-inch wide, 0.1-inch long located at the radial distance 1.5 inches from the axis of rotation. The oil has a viscosity of 3000 Saybolt universal seconds and a coefficient c of 100. The pressure differential is 1000 psi and angular speed 1800 rpm.

Under these conditions the coefficient K is given by Equation 8. With all quantities converted to the foot-pound-second system, the applicable data are: $R = 0.125$ ft, $\omega = 60\pi$ rad per sec, $\mu_0 = 0.0138$ lb sec per sq ft, $l = 0.0083$ ft, $\Delta p = 144{,}000$ psf, and $b = 0.0625$ ft. Substitution of these values in Equation 8 yields $K = 9.15 \times 10^{-11}$. This value is nearly the same as $K = 10^{-10}$ for which a curve is given in *Fig.* 5.

With $K = 10^{-10}$ and $c = 100$ in *Fig.* 5 the minimum power loss is attained at h/b equal to approximately 1.5×10^{-4} although no significant improvement in performance would be evident for values of h/b less than 5×10^{-4}.

With $h/b = 5 \times 10^{-4}$ the value of h is given by $h = 0.75 \times 5 \times 10^{-4} = 3.75 \times 10^{-4}$ inches. This value for the clearance is in accord with modern design practice for high performance.

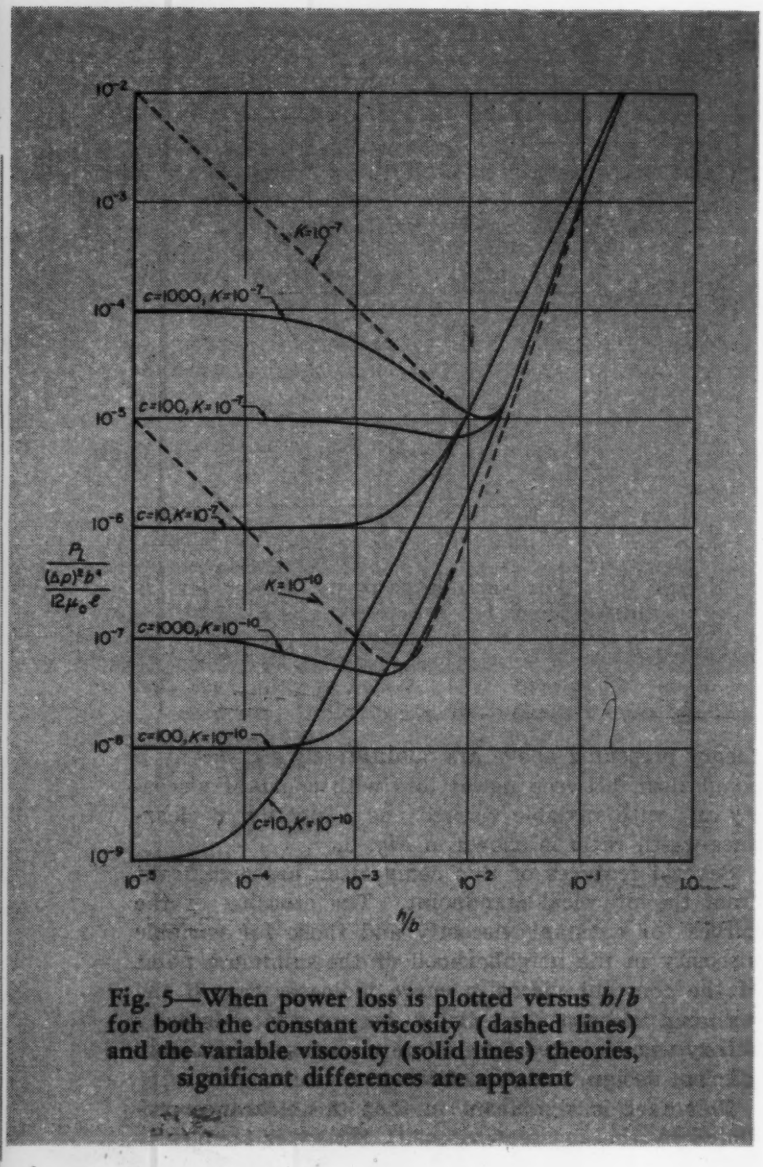


Fig. 5—When power loss is plotted versus h/b for both the constant viscosity (dashed lines) and the variable viscosity (solid lines) theories, significant differences are apparent

Conclusions: This theoretical discussion indicates general trends and possibilities which should be useful in experimental studies of positive-displacement pump and motor performance.

Economical design of such pumps and motors must ultimately consider the clearance problem and the complicated nature of the problem precludes, at least for some time to come, a completely analytical solution to the problem. Experimental studies guided by theoretical approaches should prove most useful in attaining the best designs.

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2. "Performance Criteria for Positive-Displacement Pumps and Fluid Motors"—W. E. Wilson, *Trans. ASME*, Vol. 71, 1949.
3. "Self-Induced Temperature Effects on Laminar Flow of Liquids"—W. E. Wilson and W. I. Mitchell, presented before First U. S. National Congress of Applied Mechanics, 1951.

"Perhaps we have been trying to get standardization still thinking of the old ways of design and producibility. Maybe if we thought of compietely new ways of accomplishing the design and specifically develop the product for simple producibility and simple maintenance, still endeavoring to retain the flexibility to permit the maximum utilization of technical development, we might be surprised at the lower cost standardized plane we could achieve"—W. W. DAVIES, *United Air Lines.*

AN EQUIVALENT electric circuit for any hydraulic system may be readily derived from two-terminal network analogies for each hydraulic component. Equations for system behavior may then be written and solved according to standard electric network analysis procedures. In this final article of a series, the analogies developed in two preceding articles are applied to the analysis of a hydraulic servomechanism

Electric Analogies for Hydraulic Analysis

By Sidney D. Millstone
Research Engineer
North American Aviation Inc.
Los Angeles, Calif.

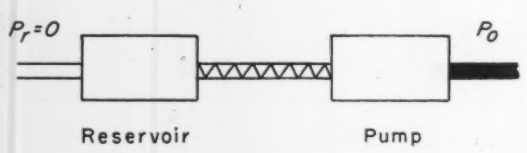
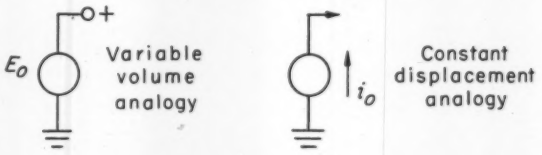
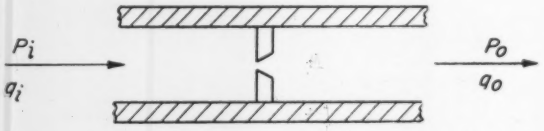
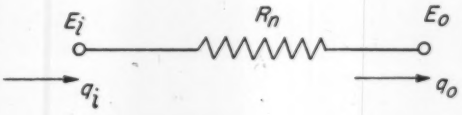
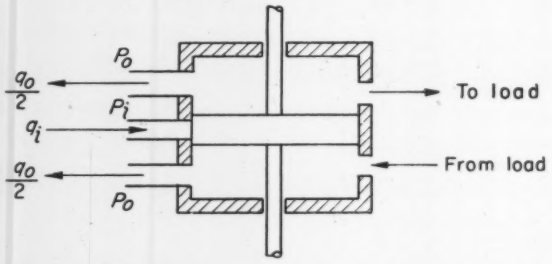
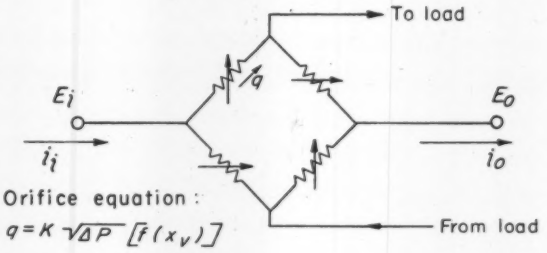
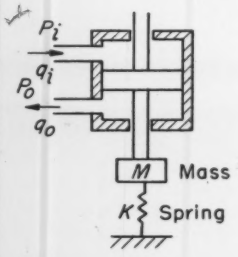
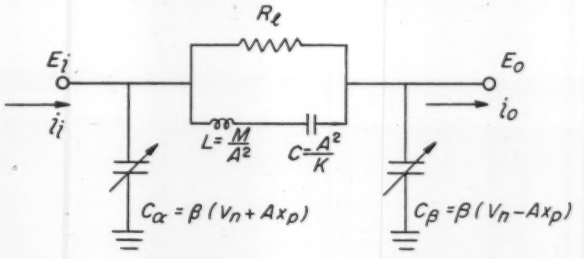
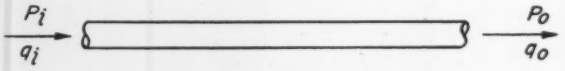
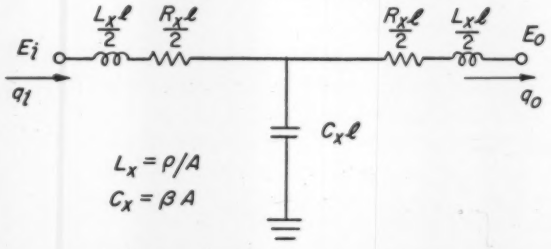
Part 3–Applying Analogy Techniques

ELECTRIC analogy techniques may be advantageously employed in the analysis of many diverse hydraulic systems. Especially where electric and mechanical components also influence system performance, these techniques provide a common basis for determination of the pertinent interrelationships. One of the most fruitful applications of electric analogies is in the field of automatic control, particularly servomechanisms.

Servomechanisms: A typical hydraulic-positioning servomechanism is shown schematically in *Fig.* 11. Close control over the output surface angle θ_o, is to be maintained by positioning the control stick with an input angle, θ_i. This control is accomplished through an error device which moves the valve spool a distance x_v, producing the required pressure for moving the actuator. Actuator displacement, x_p, controls the movement of the surface. As the surface moves, feedback cables transmit this surface position to the error device which repositions the valve spool toward neutral and returns the system to equilibrium once the desired surface position is reached.

Spool position is a linear function of the input and

TABLE 3 — ELECTRIC ANALOGIES FOR HYDRAULIC COMPONENTS

HYDRAULIC ELEMENT	ELECTRIC ANALOGY
Hydraulic Pressure, P	Voltage, E
Fluid Flow Rate, q	Current, i
Hydraulic Pumps  	**Electric Generators** 
Orifice  	**Nonlinear Resistor** 
Boost Control Valve  	**Bridge Network**  Orifice equation: $q = K\sqrt{\Delta P}\,[f(x_v)]$
Hydraulic Actuator  Leakage resistance, R_ℓ Piston area, A Fluid compressibility, β Cylinder volume, $2V_n$ Piston displacement, x_p	**Parallel Branch Network** 
Hydraulic Tubing  Tubing length, ℓ Cross section area, A Fluid compressibility and tubing elasticity constant, β Fluid mass density, ρ	**Single "T" Approximation**  $L_x = \rho/A$ $C_x = \beta A$

surface angles and may be determined from the relationship,

$$x_v = K_1 \theta_i - K_2 \theta_o \quad \ldots\ldots (54)$$

where K_1 and K_2 are constants governed by the linkage ratios in the mechanical system. Surface angle is proportional to actuator piston displacement for which the governing equation is

$$\theta_o = \frac{x_p}{r} \quad \ldots\ldots (55)$$

where r is the distance from the surface hinge point to the connection point of the actuator piston rod. In addition to Equations 54 and 55, the relationship between the actuator piston position, x_p, and the valve spool position must be found before the dynamic behaviour of the servomechanism can be completely determined.

Since the linkage ratios of Equations 54 and 55 are relatively simple to determine, calculation of the system's dynamic behaviour depends almost entirely upon the successful determination of the functional relationship between piston position and spool displacement. This functional relationship is governed by the properties of the hydraulic components and is the primary concern of this discussion. Information on basic properties and requirements of an overall hydraulic servomechanism as well as basic servomechanism theory may be readily obtained from other sources.[1, 2, 3]

Electric Circuit Analogy: Component analogies developed in the two previous articles of this series have been listed for convenience in TABLE 3. An electric circuit analogy for the hydraulic servomechanism is obtained by substituting these analogies for the hydraulic components of *Fig.* 11. The resulting circuit is shown in *Fig.* 12. Loop equations for this circuit can easily be written by the application of standard network procedures.[4]

Equations for the circuit of *Fig.* 12 are extremely difficult to solve analytically because of the nonlinear characteristics of the valve and the nonlinear condensers of the actuator circuit. For this reason, unless simplifying assumptions can be made for the net-

[1] References are tabulated at end of article.

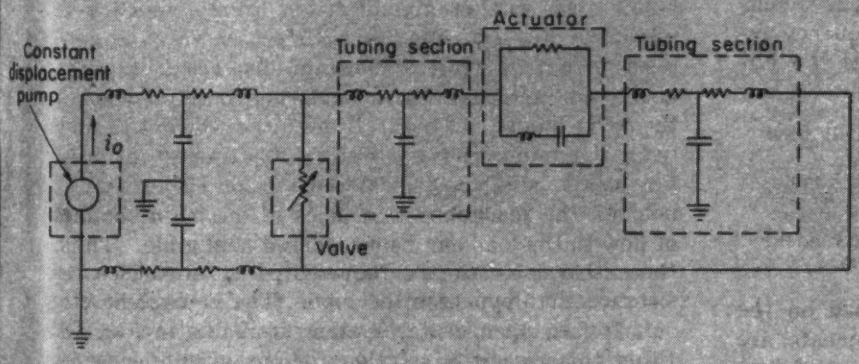


Fig. 13—Left—Linearized circuit analogy for open center valve system represents valve with single resistance that bypasses load

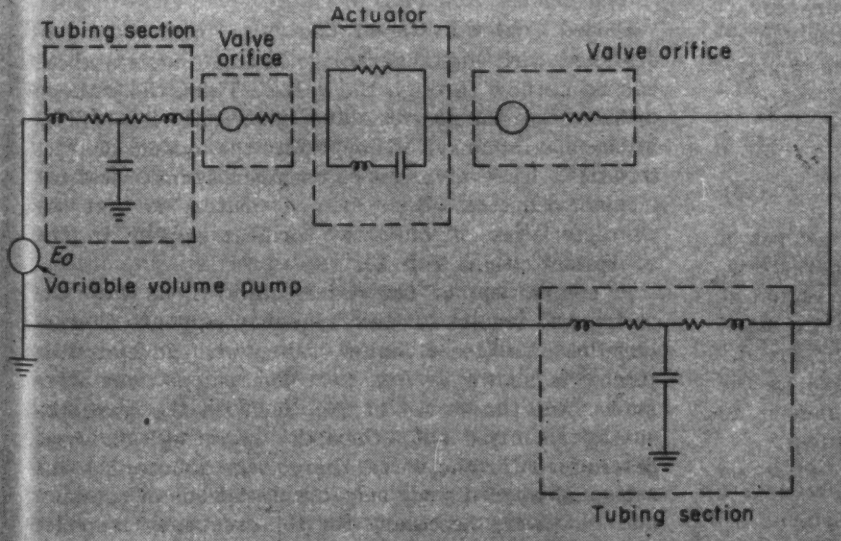
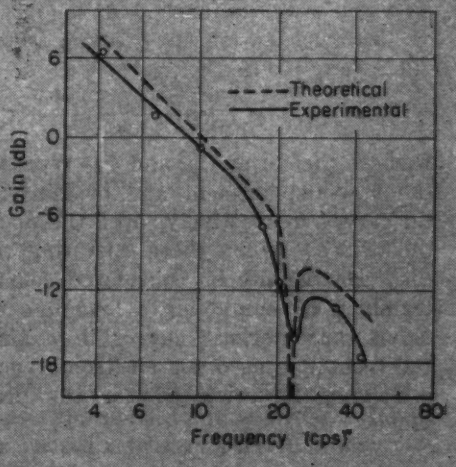


Fig. 14—Left, below—Linearized circuit analogy for closed center valve system assumes valve symmetry for displacements either side of neutral

Fig. 15—Below—Curves show comparison of theoretical and experimental results for frequency-response characteristics of a closed-center system without tubing



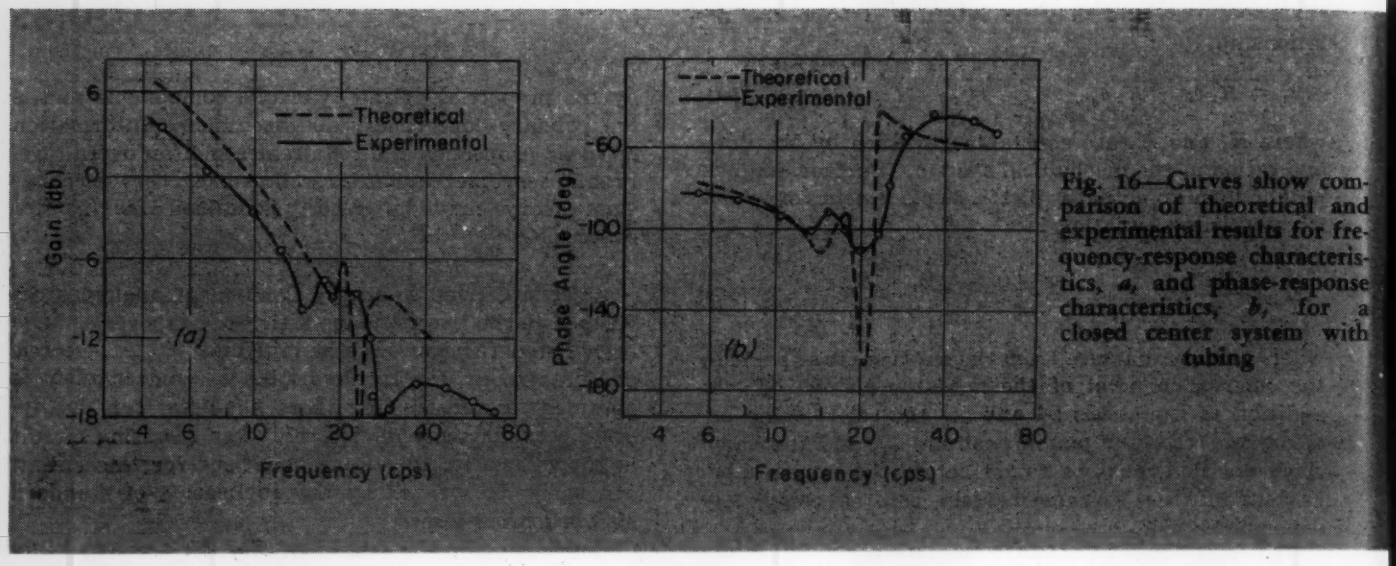


Fig. 16—Curves show comparison of theoretical and experimental results for frequency-response characteristics, *a*, and phase-response characteristics, *b*, for a closed center system with tubing

work, an analog computer would provide the most effective solution.

Linearizing Assumptions: An important part of the hydraulic servomechanism analysis is calculation of the frequency response of the actuator piston to sinusoidal inputs of valve spool position.[5] For small displacements of the spool and piston, the necessary assumptions for insuring system linearity are frequently valid and analytic solutions for the frequency response characteristics become possible. In the circuit of *Fig.* 12 these assumptions are:

1. Nonlinear condensers of the actuator circuit have a negligible effect on the circuit behaviour.
2. Nonlinear resistors representing the valve orifices can each be replaced by an equivalent circuit consisting of a voltage source in series with a linear resistor.

The second of these assumptions is based on the fact that, since only small valve displacements are considered, resulting deviations of pressure and flow rate are also small. Therefore, the differential formula for determining flow rate and pressure deviations from the neutral or steady-state values can be used. Dynamic flow rate through the orifice is given by

$$q = x_v \frac{\partial q}{\partial x} + \Delta P \frac{\partial q}{\partial (\Delta P)}$$

$$= C_{qx} x_v + C_{qP}(\Delta P) \quad \ldots\ldots (56)$$

wwhere the terms C_{qx} and C_{qP} represent the slopes of the flow-displacement and pressure-flow characteristic curves, respectively, over the operating region of the orifice. When these operating regions are small they can usually be considered constant and are determined by employing a load line technique on the valve characteristic curves in a similar manner to the technique used for electronic vacuum tubes.[7]

Solving Equation 56 for the pressure deviation yields

$$\Delta P = \frac{q}{C_{qP}} - x_v \frac{C_{qx}}{C_{qP}} \quad \ldots\ldots (57)$$

Pressure drop across the valve orifice can be considered as being composed of a generator with an output voltage given by $-(x_v)C_{qx}/C_{qP}$ and a series resistor whose resistance value is the reciprocal of C_{qP}.

Although theoretically each orifice should be replaced with its equivalent circuit, this substitution is seldom necessary in practice because the effects of some of the orifices can usually be neglected. As a result even further simplification of the network is possible. For example, an open center valve is supplied with fluid from a constant displacement pump and is characterized by an underlap in the design of the valve lands. At neutral, therefore, the entire flow from the pump passes through the leakage orifices. For small valve spool displacements on either side of neutral, the resistance of orifices in the main channel of flow to the load can be considered negligible. Thus, the entire valve can be represented by an orifice resistance that bypasses the load. The equivalent circuit for an open center system is shown in *Fig.* 13. From this circuit a solution for the system may be determined.[1]

Closed Center Systems: The closed center valve is designed with high overlap so that at neutral there can be no flow through the valve. Thus, the leakage orifices have infinite resistance since only the orifices in the main channel of flow affect the system characteristics. The valve can be assumed symmetrical for displacements on either side of neutral so that the characteristics of only two orifices appear in the equivalent circuit, *Fig.* 14.

A comparison of theoretical calculations with experimental results for the frequency response characteristics of a closed center system with no hydraulic tubing is shown in *Fig.* 15. The calculations were made from the circuit of *Fig.* 14, with the transmission line shorted out. Once the operating point was determined for the valve, the voltage source, E_o, was set equal to zero since only the deviations of pressure and flow were necessary for the frequency response calculations.

The calculations were made by assuming the valve

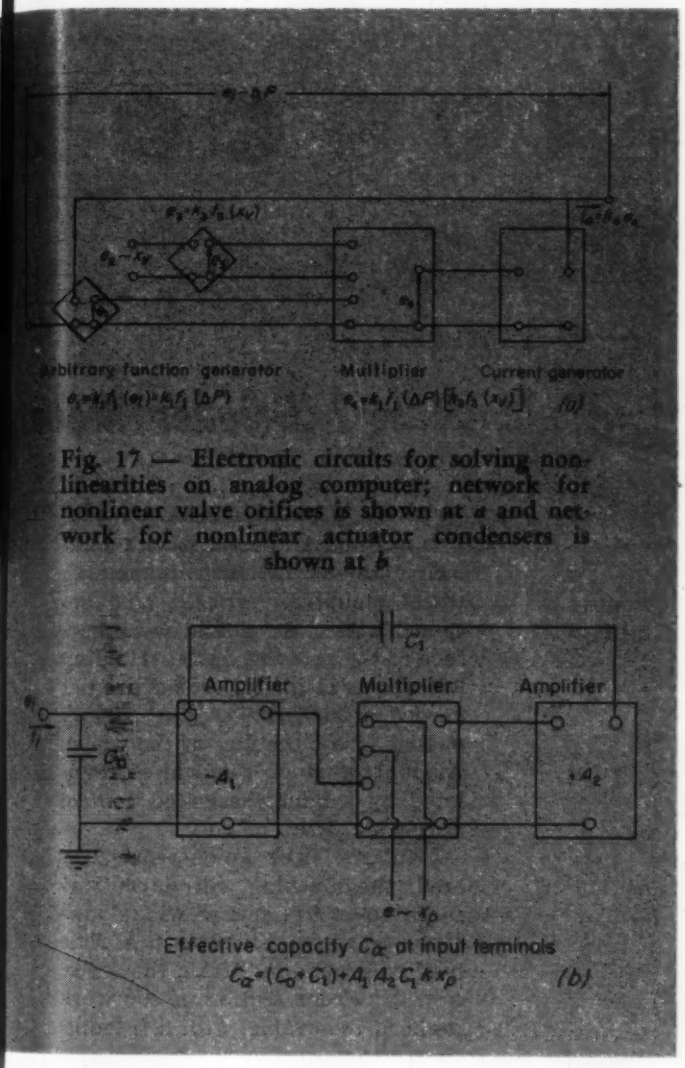


Fig. 17 — Electronic circuits for solving nonlinearities on analog computer; network for nonlinear valve orifices is shown at *a* and network for nonlinear actuator condensers is shown at *b*

orifice generators to be supplying sinusoidal voltages proportional to x_v and in accordance with the source voltage as indicated in Equation 57. Sinusoidal response of the actuator was calculated from the voltage drop across the actuator condenser, this quantity being directly proportional to the piston displacement. The response was then determined from the ratio of amplitudes of piston displacement to valve spool displacement.

A similar calculation for the circuit of *Fig.* 14, using a "T" network approximation for 14 ft of aluminum tubing between both pump and valve and valve and reservoir was also checked experimentally. These results are given in *Fig.* 16.

Although the results presented in *Figs.* 15 and 16 indicate a very close correlation between theory and experiment, approximately 50 per cent of the cases tried failed to yield any correlation. The reason for these discrepancies has been traced to the valve approximations. Either the operating range of the valve characteristics is too large to permit the assumption of constant values for C_{qx} and C_{qP} or the dynamic pressure-flow characteristics differ markedly from static characteristics. In any case a more reliable criterion for determining valve behavior must be found before conclusive statements as to the usefulness of the approximate analogy of *Fig.* 14 can be made.

Non-Linearities: As stated previously, an ideal technique for studying hydraulic system dynamics is offered by the nonlinear analog computer.[6] With such a device both the nonlinear characteristics of the valve and the nonlinear condensers of the actuator circuit can be included so that more complete dynamic data can be obtained. Electronic circuits for producing these nonlinearities are shown in *Fig.* 17.

Acknowledgement with appreciation is extended to W. R. Monroe, James E. Campbell and R. G. Bang of the Systems and Tactics Group for many valuable suggestions and important contributions to this series of articles.

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Correction

In the article "Simplified Gear Design" (MACHINE DESIGN, November, 1952, Page 125) by W. A. Tuplin, a typographical error occurred in Equation 10 for determination of normal backlash. Correctly expressed this equation is

$$B = \frac{0.65\,(S-1)^2 \cos^2 \psi}{CP_n^2} \qquad (10)$$

The author wishes to emphasize that this equation, as well as Equations 6, 7, 8 and 9, are based on a 20-degree normal pressure angle in agreement with the derivation presented in the left-hand column of page 129. He also has noted that Equation 10 is modified for the case of equal gears. The normal backlash, B is then

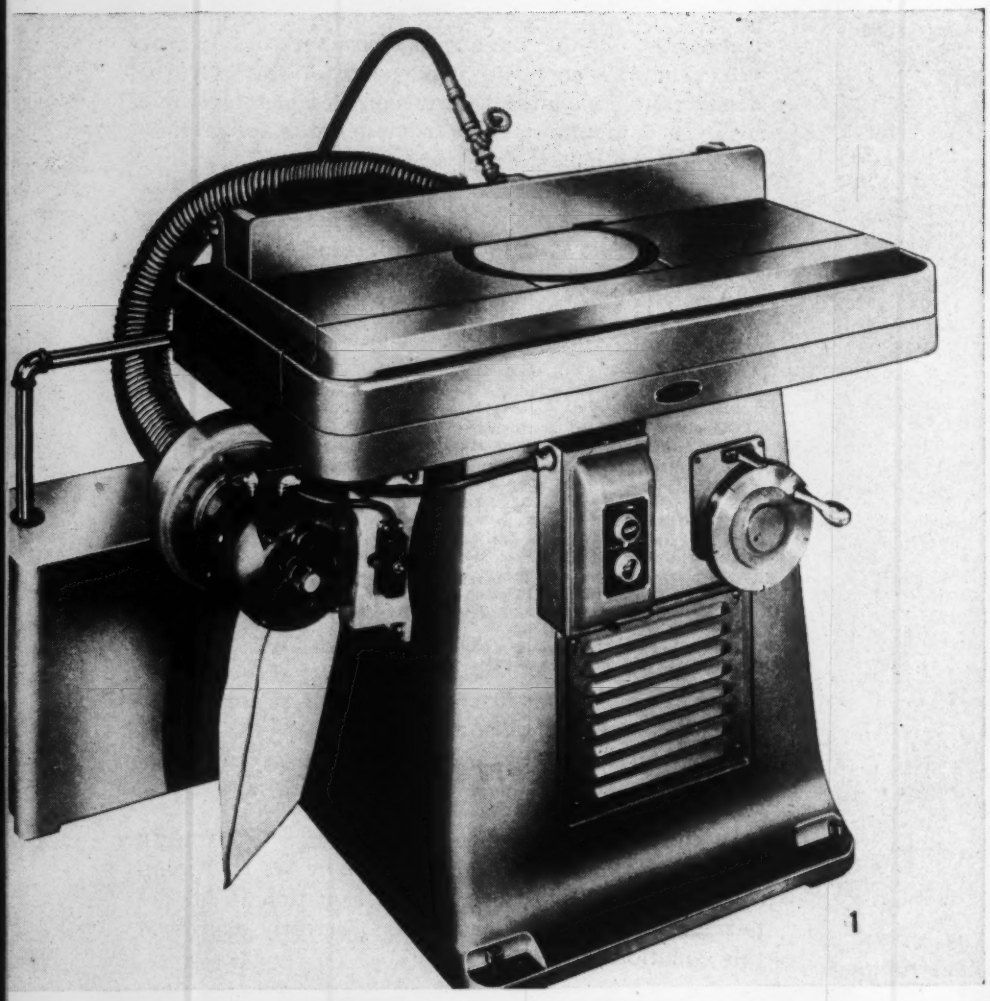
$$B = \frac{0.65\,(2S-4)^2 \cos^2 \psi}{CP_n^2}$$

Comparing this equation with Equation 10 reveals that the difference appears in the quantity in brackets. The difference occurs because the factor corresponding to the addendum of the pinion is 3, whereas for equal gears it is S.

"I believe we need the practical, informed and so intellectually honest approach to public affairs that the engineer has brought to our private industrial affairs."—GLENN B. WARREN, *general manager, Turbine Div., General Electric Co.*

CON

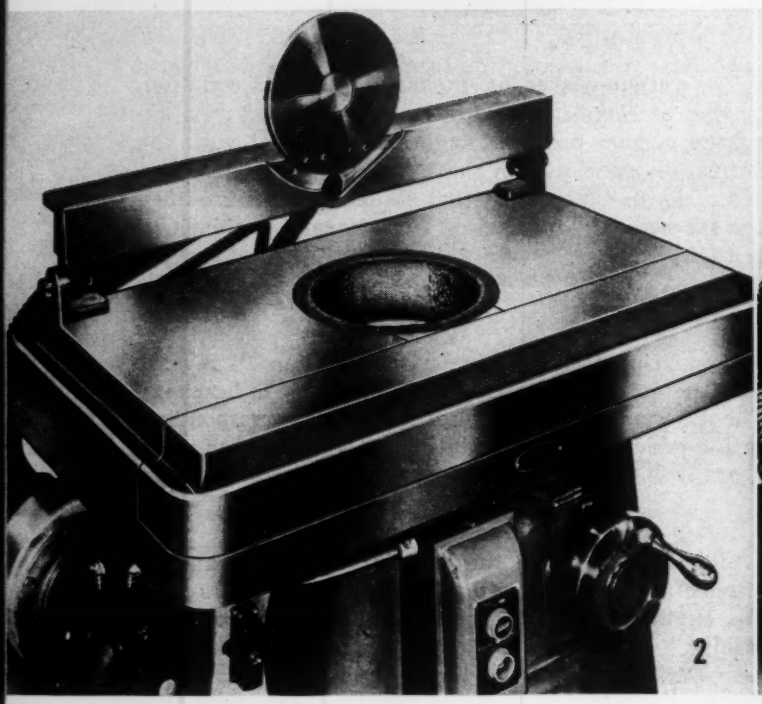
Grinder Mounts



1

A NEW grinding machine, *Fig.* 1, finishes flat surfaces with a 12-inch diameter cylindrical grinding wheel mounted vertically and recessed within the actual work surface of the grinding table. Holding fixtures or magnetic chucks are not needed, since workpieces are simply passed across the face of the wheel. Amount of stock removal is regulated by a handwheel feed control governing depth of cut.

With the back guide fence lowered, the machine will finish surfaces up to 9½ inches wide; however, areas up to 12 inches wide may be ground by lifting the fence, *Fig.* 2. Front section of the work table is removable, *Fig.* 3, permitting grinding of parts having side



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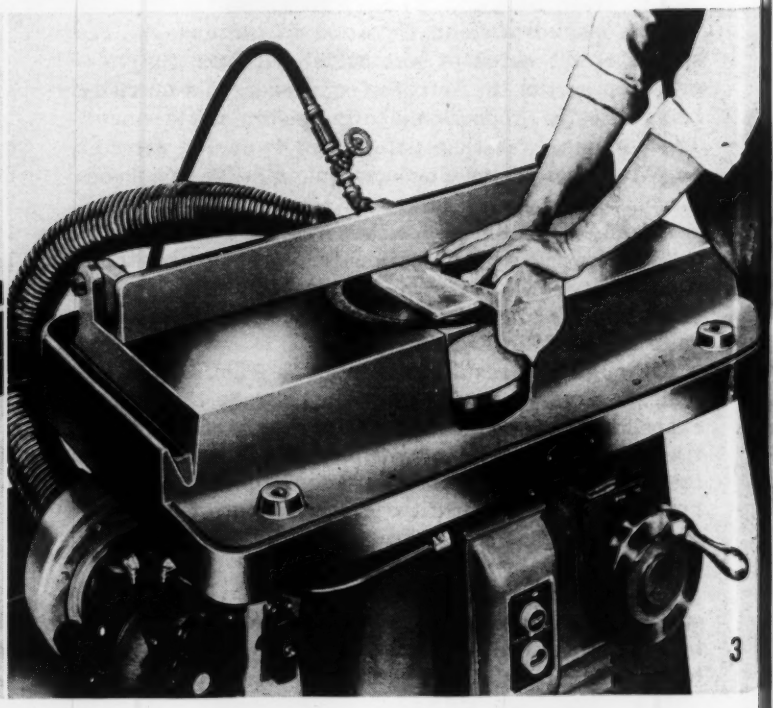


3

TEMPORARY DESIGN

Cylindrical Wheel Vertically

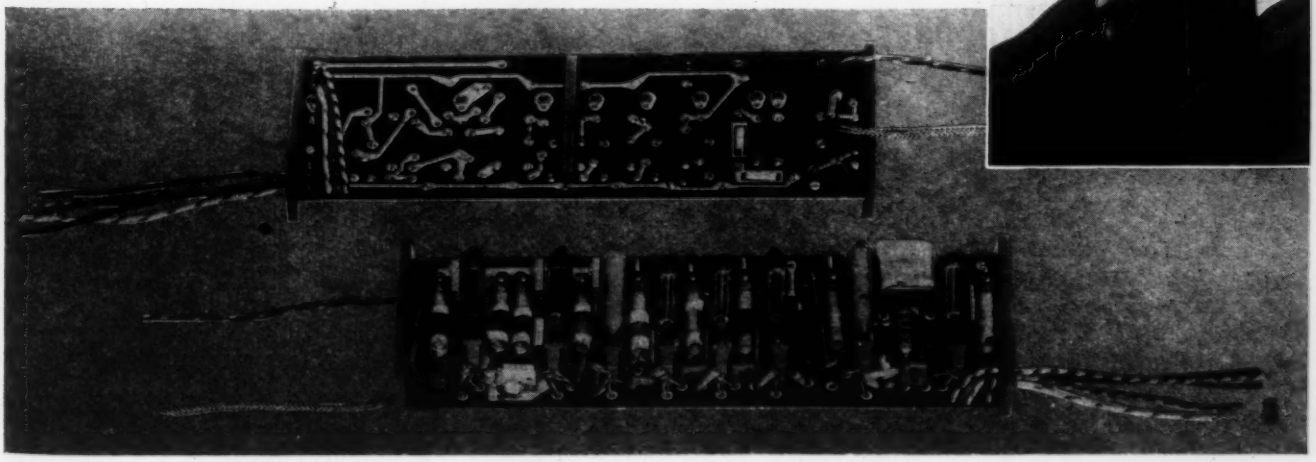
obstructions which cannot ordinarily be ground in a flat-bed grinder. In many instances, surfaces at right angles may also be ground, since removal of the front section permits workpiece shoulders to contact the grinding wheel.

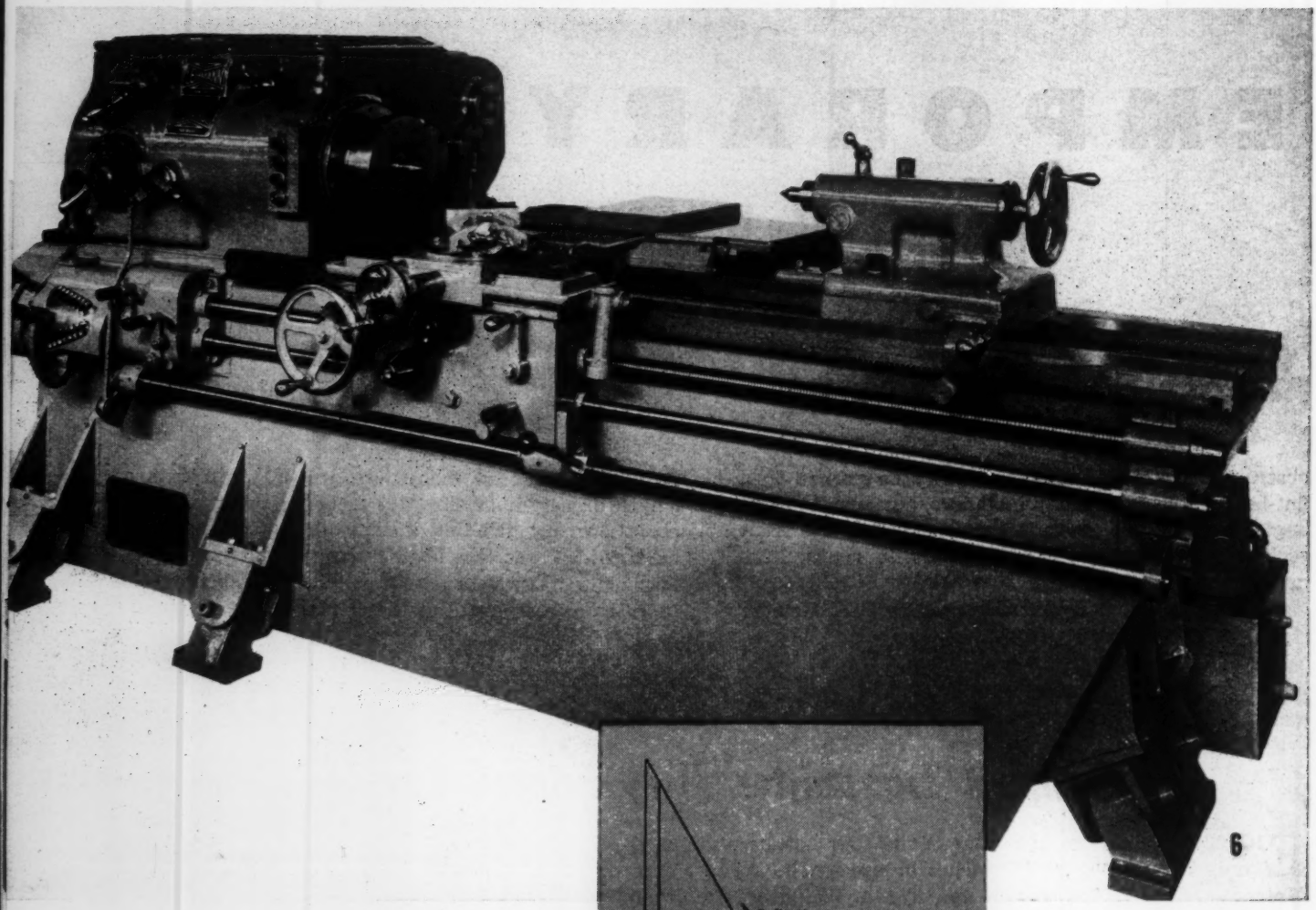
The surface grinder, manufactured by PDQ Grinder Co., is designed so that there are no limitations on length or height of the part to be finished. Dust removal for dry grinding is through an opening in the back guide fence to a flexible hose, and for wet grinding, coolant flows through a smaller hole in the guide fence from a separate motor-driven coolant system.

Compact Transmitter Uses Printed Circuit

EIGHT subminiature tube stages and four batteries are condensed into a case only 7⅜ by 2½ by 1¾ inches in size by the use of a printed circuit in the Motorola Micro-Talkie transmitter, *Fig.* 4. Weight of the crystal-controlled, frequency-modulated transmitter is only 1 pound 13 ounces, although power output is more than 25 milliwatts with a 15 kilocycle deviation in the operating-frequency band of 152-174 megacycles.

Chassis on which the circuits are mounted is a flat piece of bakelite, *Fig.* 5. Holes are first punched and "wiring" is plated on after punching. Tubes and other circuit elements are mounted on one side of this printed circuit, while two B-batteries and two A-batteries are mounted on the opposite side. The complete assembly is housed in a seam-welded metal case with a rigid, chrome-plated loop antenna that doubles as a carrying handle. An actuating switch, completely covered with weatherproof rubber patch, is the only moving part.





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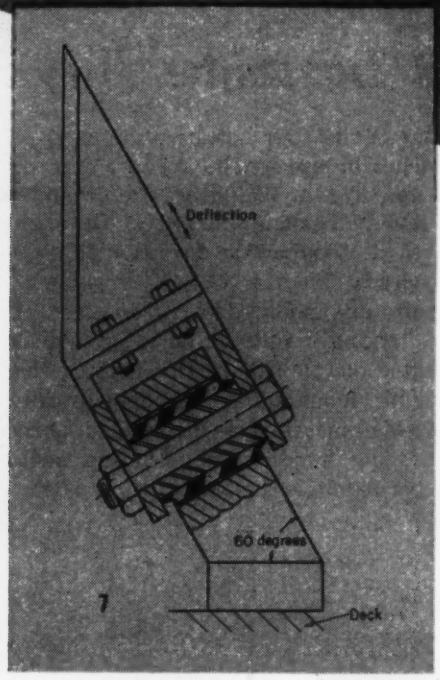


7

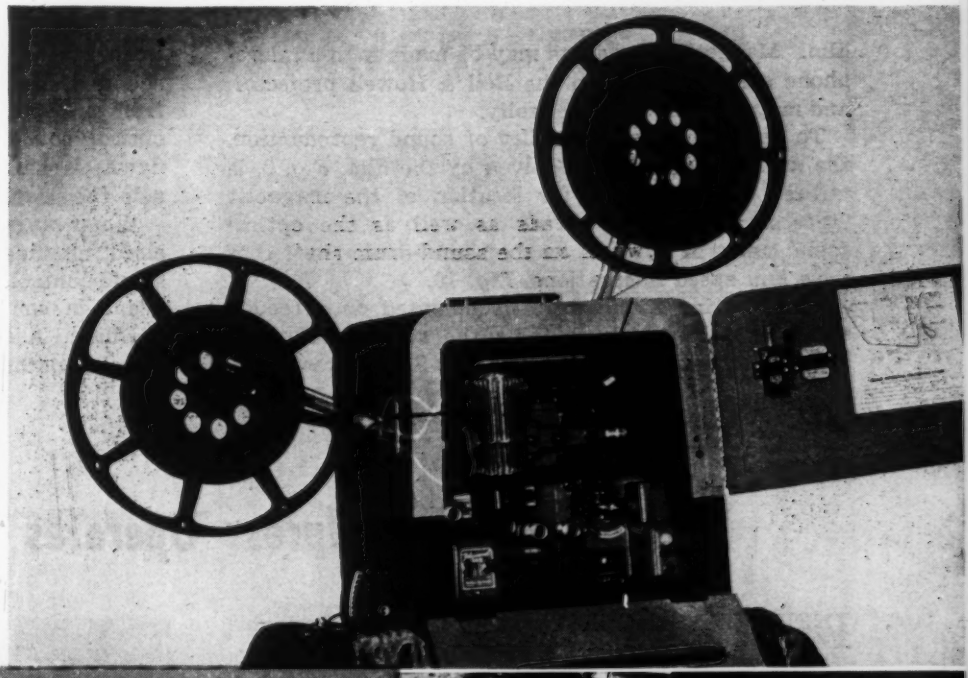
Welded-Base Lathe with Shock Absorbers

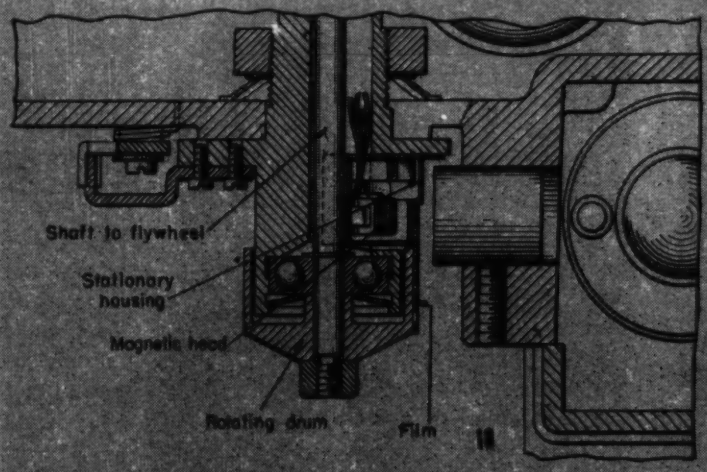
ORIGINALLY designed to withstand impact and stress from heavy seas and naval gunfire, the Lehmann Machine Co. engine lathe, *Fig.* 6, has a welded base and shock-absorber mounting. Retention of accuracy despite shock loading, and light weight to limit deck loadings aboard ship, were both necessary.

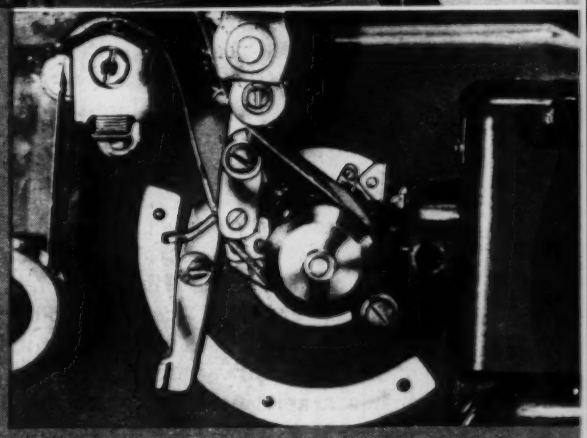
Welded construction accomplishes the saving in weight, but the lathe bed is wider than standard to provide additional strength and cross-member supports compensate for the thinner bed walls. Five specially designed feet carrying Lord bonded-rubber mountings, act as universal mountings and absorb shock. Brackets are inclined 60 degrees from the horizontal so that deflection is along the radial (stiff) axis of the rubber mounting, *Fig.* 7. Sound dampening was also accomplished by filling pockets in the interior of the weldment with concrete to lower the pitch of normal lathe operating noise.

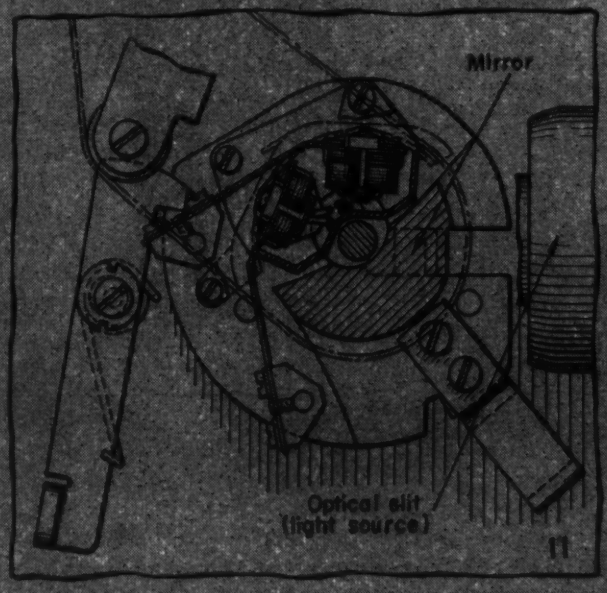
Projector Has Optical-Magnetic Sound Head

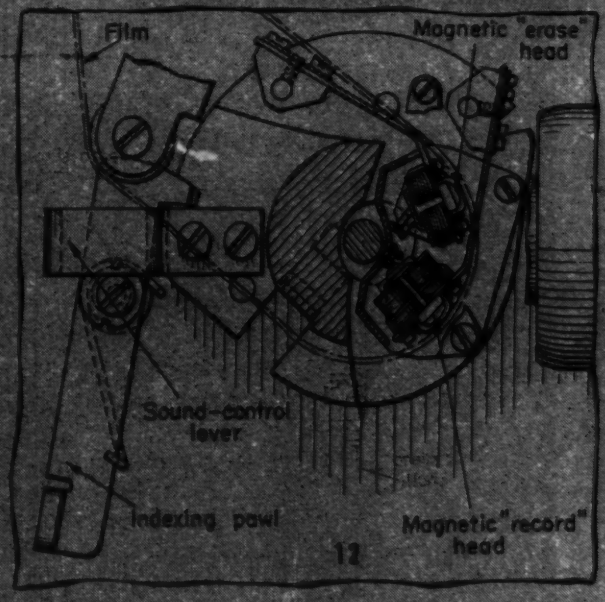
MOTION pictures having optically recorded sound, and 16-millimeter film with a magnetic sound track for recording and playback, can both be shown on the Filmosound 202 projector, *Fig.* 8. Both types of sound track may be incorporated on the same film, since the magnetic strip is placed between perforations and edge of the











film. Magnetic recordings may be made with a microphone system built into the Bell & Howell projector, and may be erased magnetically.

To permit maximum fidelity of sound reproduction, the sound drum, friction-driven by the film, *Fig.* 9, is utilized in the system for location of the magnetic "record" and "erase" heads as well as the optical sound unit. A flywheel on the sound-drum shaft controls film speed fluctuations, *Fig.* 10.

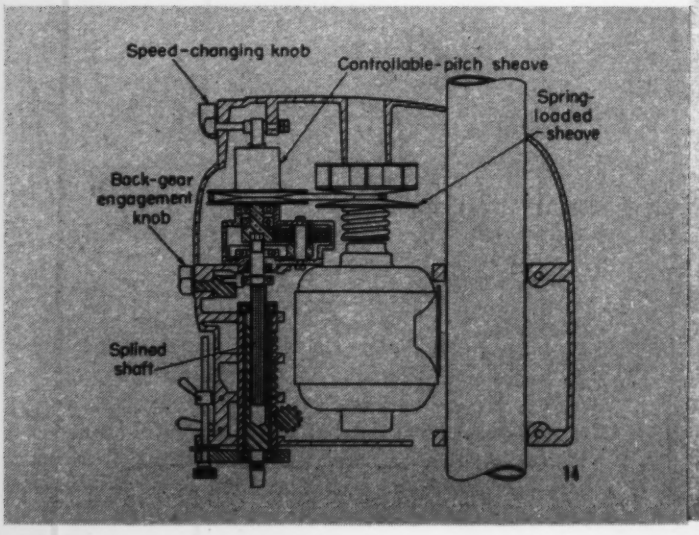
The rotating sound drum is mounted on a second rotatable part which contains the sound heads and supports the sound-drum bearing. Sound track portions of the film overhang the edge of the rotating sound drum. In the position shown in *Fig.* 11, light from an optical slit passes through the overhanging optical sound track and is reflected parallel to the flywheel shaft by a mirror to a photoelectric cell inside the projector housing.

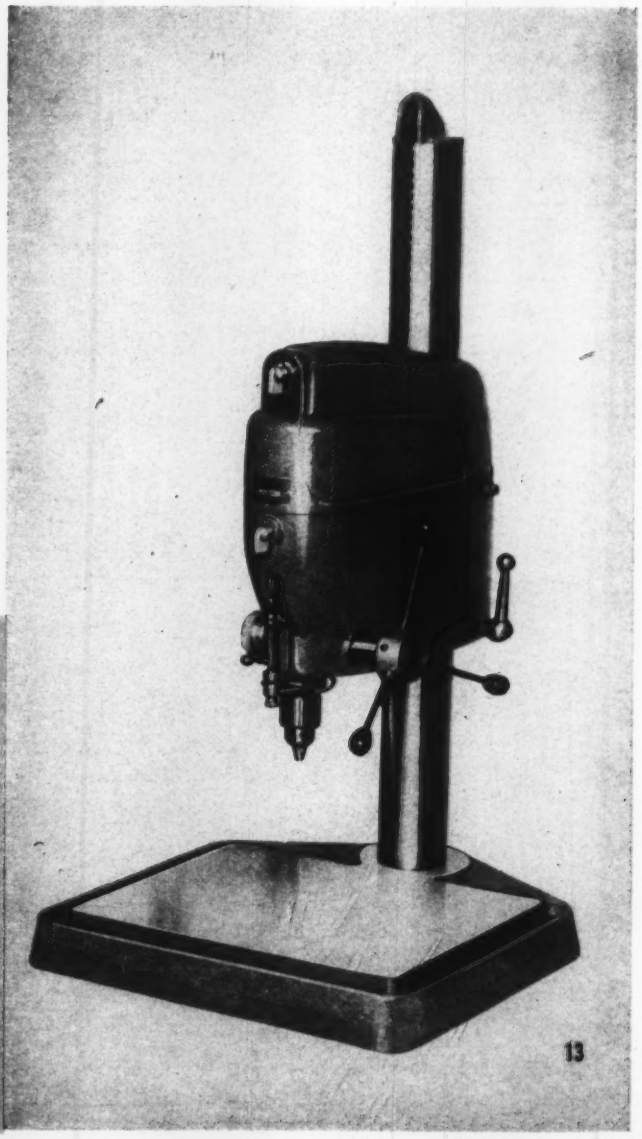
When magnetic sound recording or playback is desired, an indexing pawl, *Fig.* 12, is released and the sound-control lever is shifted to bring both magnetic heads in contact with the magnetic sound track on the film. A small retractable rubber roller holds the film in contact with the magnetic "record" head.

Variable-Speed Drillpress Operates in Two Ranges

INFINITELY variable speed changing in a double range is accomplished in the Electro-Mechanico Co. drillpress, *Fig.* 13, by a combination of variable-pitch sheaves and back-gearing. Either of the two speed ranges, 150 to 1000 rpm or 600 to 4000 rpm, can be selected by shifting an involute-splined shaft axially, *Fig.* 14, thus providing engagement through either back-geared or direct drive, respectively. Infinite speed changing within each of these overlapping ranges is provided by a set of variable-speed sheaves at fixed center distances. Within each range, speed can be changed while running.

Completely enclosed, the Model 601 drillpress uses a standard ½-horsepower, 1740-rpm induction motor, either single or three-phase. Bearings for the quill, which has a split housing for takeup and clamping, are located at extreme ends for stability and accuracy. Precision ball bearings used at other locations are all preloaded, lubricated and sealed.





Swashplate Mechanisms

How to determine dynamic characteristics of these mechanisms which are useful in converting rotary to reciprocal motion.

By R. Hadekel
Consulting Engineer
London, England

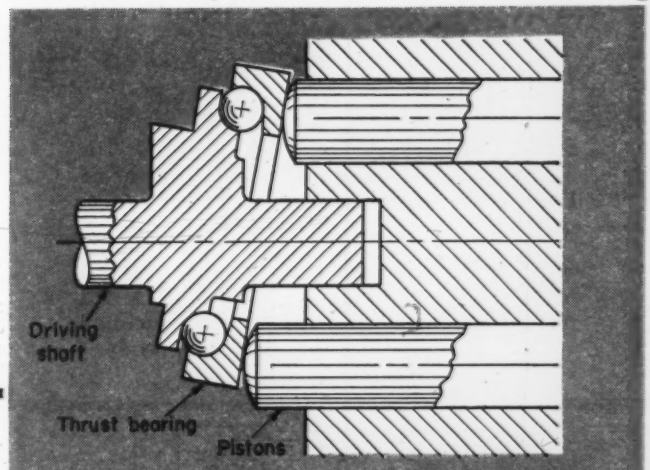
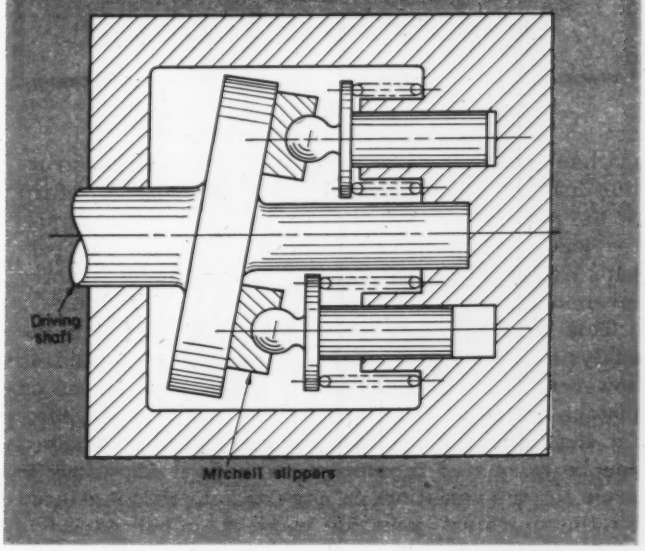


Fig. 1—Nonrotary form of swashplate mechanism has a stationary cylinder block and transmits rotary motion of drive shaft to pistons through an inclined bearing track

Fig. 2—Modification of nonrotary mechanism of *Fig.* 1 employs Michell slippers to transmit drive shaft motion to pistons



COMPACT and efficient, swashplate mechanisms find application in pumps, hydraulic motors and other machines where a conversion of rotary to reciprocal motion is required. Although several forms of these mechanisms are in use, their characteristics are essentially the same and may be readily analyzed by rational means. In this article the various mechanism forms will be discussed and a method of analysis will be presented.

Forms: One possible form of the swashplate mechanism is shown in *Fig.* 1. The driving shaft carries an inclined thrust bearing with the bearing track acting as a path on which the piston heads run. In this form, the piston heads are spherical—a construction which the author believes to be the optimum for reasons which will be explained later. Sometimes the piston heads are made conical to obtain line, rather than point, contact but this inevitably leads to sliding at the contact line.

In some cases, a plain track is used instead of a ball bearing. The pistons bear on the track through Michell slippers, which give surface contact, *Fig.* 2. The slippers should preferably be of segmental form and must then be kept in correct orientation. One method of insuring orientation employs an alignment ring, *Fig.* 3; proper clearance must be sufficient to allow for the location of the piston heads on an ellipse instead of on a circle. The value of this construction is doubtful, especially in view of the high efficiency achieved with the ball bearing form of the mechanism. In either case, the pistons are usually returned by springs.

If an angular velocity equal and opposite to that of the driving shaft is superimposed on the whole mechanism, the driving shaft then becomes stationary and can be made into a body. The cylinder block now rotates and can be made the driven member. This form, which is the "rotary" inversion of the mechanism of *Fig.* 1, is shown in *Fig.* 4. Obviously the relative motions of the various components are identical in both types; in particular, the reciprocating motion of the pistons is simple harmonic in form.

Another similar type of mechanism which utilizes a wobbleplate is shown in *Fig.* 5. The wobbleplate must be prevented from rotating within the body of the mechanism. Several methods of attachment are possible. In this case the wobbleplate is fixed to the body through a universal joint. As compared to the

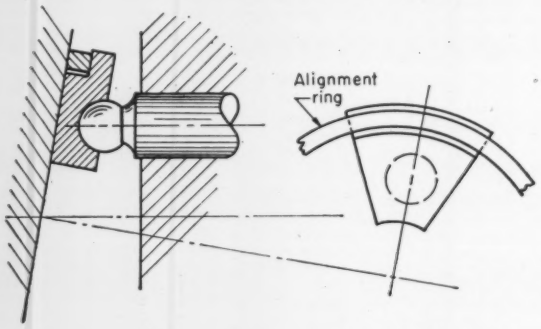


Fig. 3—Above—Construction details for Michell slippers employed in mechanism of *Fig.* 2 show preferred segmental slipper form and method of attaching alignment rings

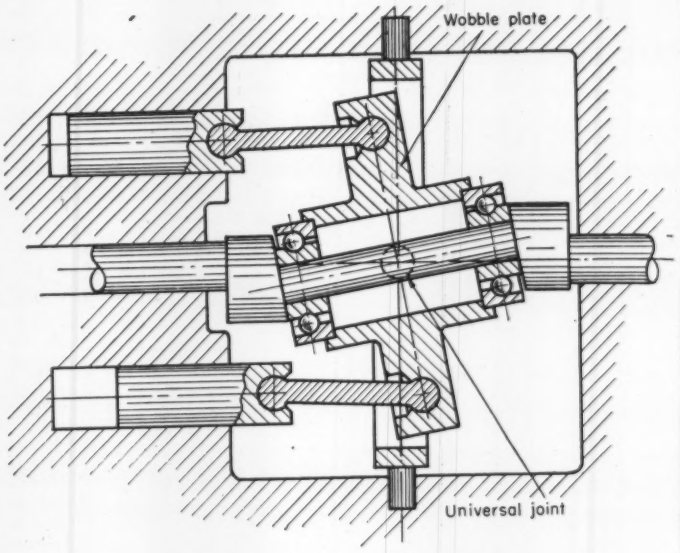
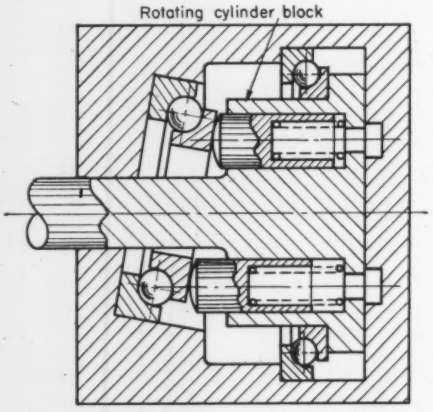


Fig. 4—Below—Rotary form of swashplate mechanism has a rotating cylinder block and piston action is provided by an inclined track mounted in the stationary body



mechanisms of *Figs.* 1, 2 and 4, this form of construction has the advantages of providing positive return of the pistons and reducing the inclination of the piston load. However, it is more complicated and perhaps not always more efficient. Two common rotary inversions of this mechanism are shown in *Fig.* 6.*

This article will be primarily concerned with the analysis of the mechanism forms in *Figs.* 1 and 4; however, conclusions regarding the inertia forces on pistons are also applicable to the type in *Fig.* 2. Also, for the mechanisms in *Figs.* 5 and 6, forces involved can be calculated by similar methods if allowance is made for the variations in angular velocity introduced by the universal joint, or whatever other device is used to restrain the wobbleplate, and for the additional geometric factors resulting from the use of connecting rods.

Kinematics: For purposes of analysis, piston heads are assumed to be portions of a sphere of radius r. Also, an initial assumption will be made that the axis of the bearing intersects that of the cylinder block at a point in the plane containing the centers of curvature of the piston heads, *Fig.* 7.

In the determination of the relative velocities of the piston heads and track, it is immaterial whether the nonrotary mechanism of *Fig.* 1 or the rotary form of *Fig.* 4 is considered. Actually, the latter is much easier to analyze. If the cylinder block is driven at an angular velocity ω, friction of the pistons will drive the bearing track at some velocity which will be denoted by Ω. The pitch circle radius of the pistons is a and the angle of inclination of the swashplate is α. These quantities are shown in *Fig.* 7, where (a) is an end view on the cylinder block, (b) a side view projected on to a plane perpendicular to that of the swashplate, and (c) a view on the plane of the track.

At the instant considered, one particular piston has its axis at X in view (a). Its contact point with the track will then be at P' in view (b), which projects into P in view (a) and P'' in view (c). Coordinates of P'' are

$$x = a \cos \theta$$

$$y = a \sin \theta \sec \alpha$$

where θ is the angle of rotation of the cylinder block measured from the axis OO' of *Fig.* 7.

For convenience, analysis will begin with the condition (which never occurs in practice) in which the pistons do not rotate relative to the body; that is, the pistons rotate at an angular velocity $-\omega$ relative to the cylinder block. For this condition the contact point P is always the same point of the piston head. Since $\omega = d\theta/dt$, the velocity of the point P'' is given by the components

$$V_{PX} = \frac{dx}{dt} = -a\,\omega \sin \theta$$

$$V_{PY} = \frac{dy}{dt} = a\,\omega \cos \theta \sec \alpha$$

A point Q on the track surface coinciding with P has the velocity components

$$V_{QX} = -y\,\Omega = -a\,\Omega \sin \theta \sec \alpha$$

$$V_{QY} = x\,\Omega = a\,\Omega \cos \theta$$

*R. Hadekel—*Displacement Pumps and Motors,* Sir Isaac Pitman & Sons Ltd., London, 1951.

Fig. 5—Left — Positive return of pistons and reduced inclination of piston load are provided in this mechanism which utilizes a nonrating wobbleplate attached through a universal joint

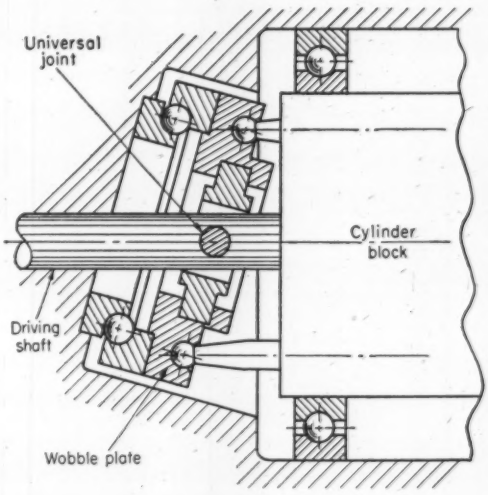
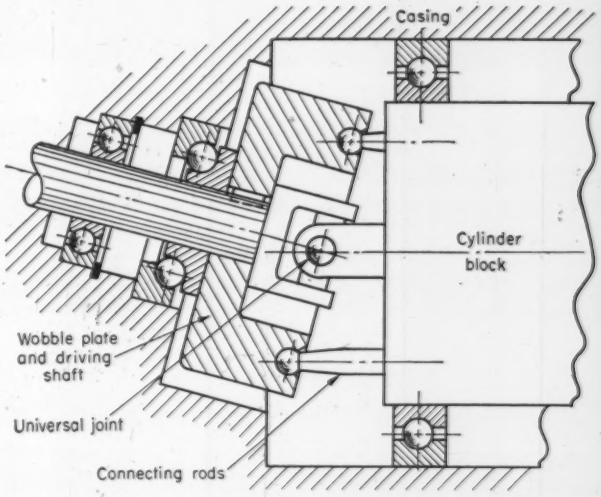


Fig. 6—Right—Rotating cylinder blocks and wobbleplates are utilized in these two rotary inversions of the mechanism in *Fig.* 5 to provide the desired motion conversion



The relative velocity of sliding of the piston head on the track, V_R, will then have the components

$$V_{RX} = V_{PX} - V_{QX}$$

$$V_{RY} = V_{PY} - V_{QY}$$

When $\Omega = \omega \sec \alpha$, $V_{RY} = 0$. If V_{RX} can also be reduced to zero, there will be no relative sliding; the piston head will have a pure rolling motion on the track. This would obviously result in high mechanical efficiency.

If the pistons rotate about their axes with an angular velocity, relative to the casing, of μ, a component of velocity, $-r\mu \sin \alpha$, will be added to V_{PX} but V_{PY} will be unaffected. Thus, if μ has the correct magnitude (which will vary as the cylinder block rotates), the required condition of zero relative sliding is achieved, still provided that $\Omega = \omega \sec \alpha$.

If the track is quite free to rotate and the pistons can rotate freely in their bores, friction between pistons and track will drive the latter at just the right speed. Also, the pistons will rotate in their bores at the correct speed. At least this would be the case if the rotations in question were unopposed by any friction forces. In practice, however, this condition is approached closely, and any residual sliding caused by parasitic friction forces is very small. For some swashplate pumps the track carries a bevel gear which is driven by a crown gear on the cylinder block. Although this gives the correct relationship, $\Omega = \omega \sec \alpha$, without relying on friction drive, it is probably an unnecessary refinement.

Therefore, if the pistons are free to rotate within their bores and drive the track through friction, the relative motion at the point of contact of piston head and track is at least a very close approximation to pure rolling, leading to high efficiency and low wear. This conclusion, of course, applies only if the piston heads are spherical—hence the earlier remarks about the doubtful advantage of using conical piston heads or Michell slippers.

The particular mechanism geometry which has been discussed, with the axis of the track passing through the intersection of the plane of the centers of curvature of the piston heads with the cylinder block axis, is not necessarily the optimum. If the axis of the track is displaced by an amount e, *Fig.* 7, the track will now rotate about a center O_1'' which is equivalent to a rotation about the original center O'' plus a translation $-e\Omega$ in the x direction. This gives

$$V_{QX} = -\Omega (a \sin \theta \sec \alpha + e)$$

and with $\Omega = \omega \sec \alpha$,

$$V_{RX} = a\omega \sin \theta \tan^2 \alpha - r\mu \sin \alpha + e\omega \sec \alpha$$

By letting $V_{RX} = 0$, the value of μ required to give pure rolling is obtained. However, μ is the angular velocity of the pistons relative to the casing. The angular velocity of the pistons relative to the cylinder block is then

$$\mu - \omega = \omega \left(\frac{a \sin \theta \sin \alpha}{r \cos^2 \alpha} + \frac{e}{r \cos \alpha \sin \alpha} - 1 \right)$$

The first term within the brackets represents a to-and-fro rotation of frequency equal to the rotational frequency of the shaft or rotor. The second and third terms together represent a steady rotation, the velocity of which depends on the quantity e. In particular, the steady rotation can be made equal to zero if

$$e = r \sin \alpha \cos \alpha$$

Required position of the track axis to achieve this condition is shown in *Fig.* 8. With this geometry, the rotation of the pistons within their bores is purely oscillatory and the angular velocity is

$$\mu - \omega = \frac{\omega a \sin \theta \tan \alpha \sec \alpha}{r}$$

The geometry shown in *Fig.* 8 represents perhaps the

Fig. 7—Right—Line diagram for analysis of kinematic characteristics of mechanisms in *Figs.* 1 and 4 includes end view of cylinder block, (*a*); side view, (*b*); and a view on the plane of the track, (*c*)

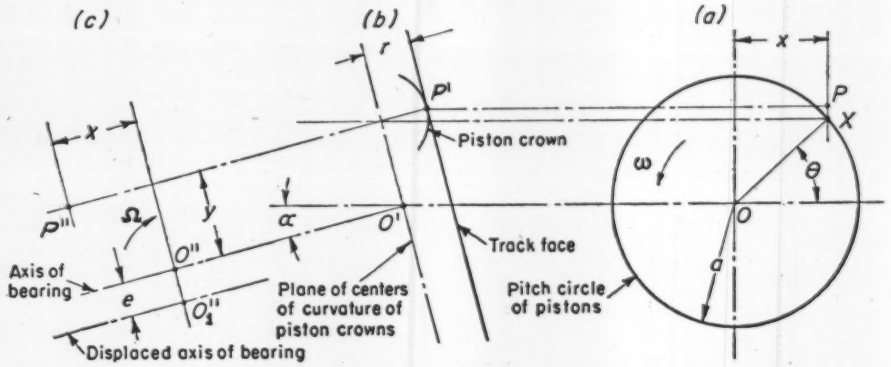


Fig. 8—Optimum position of track axis shown in this line diagram provides for minimum dissipation of energy in rotating pistons in their bores

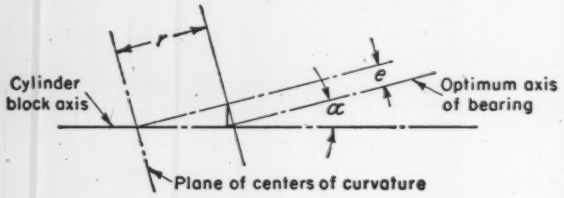
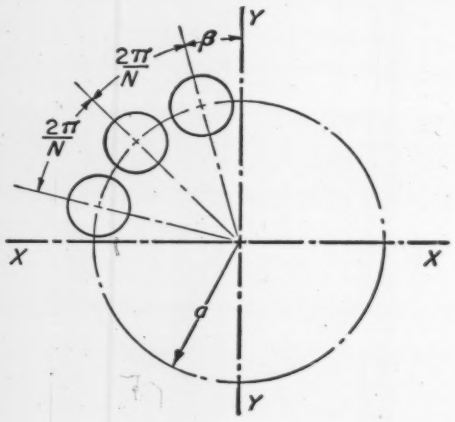


Fig. 9—Below—Line diagram for analysis of piston inertia forces shows angular relation of the pistons in the cylinder block



most desirable configuration, since it implies the least dissipation of energy in rotating the pistons in their bores.

Piston Inertia Forces: If N pistons are equally spaced at angles of $2\pi/N$ on a pitch circle of radius a and α is the swashplate angle, the half-stroke, s, is then

$$s = a \sin \alpha$$

In *Fig.* 9, YY is the dead center axis of the swashplate and β is the angular displacement of the first piston from dead center. If m is the mass of the piston, the inertia force, F_i, is

$$F_i = ms\ \omega^2 \cos \beta$$

The moment, M_{yy}, about the YY axis is

$$M_{yy} = ms\,a\,\omega^2 \cos \beta \sin \beta$$

and the moment, M_{xx}, about the XX axis is

$$M_{xx} = m\,s\,a\,\omega^2 \cos^2 \beta$$

Forces and moments due to any piston, r positions from dead center, are obtained by replacing β with $\beta + [2\pi(r-1)/N]$ in the previous expressions. Resultant forces and moments are obtained by summing the appropriate terms for all of the N pistons, from $r = 1$ to $r = N$. This summation process is somewhat involved and the detailed calculations may be omitted. The final result is that the net force for all N pistons is zero and the net moment about the YY axis is also zero. There is, however, a resultant moment, M_{xp}, about the XX axis, which is

$$M_{xp} = \frac{N\,m\,\omega^2\,s\,a}{2}$$

This moment is constant in magnitude and acts about an axis perpendicular to the dead center axis of the swashplate. Hence for a rotary mechanism such as that of *Fig.* 4, the moment is constant in direction as well as in magnitude and will have no effect beyond exerting a reaction on the mounting of the machine. In a nonrotary mechanism such as that of *Fig.* 1, the axis about which the moment acts rotates with the driving shaft and the resultant effect is therefore the same as that of a dynamic out-of-balance.

If the pistons have a motion of to-and-fro rotation within their bores, as explained previously, each piston will in addition produce an inertia torque. The torques on the N pistons follow exactly the same law as the inertia forces due to sliding, and their resultant is also zero. Thus no unbalance is created by this effect.

Track Inertia Forces: In the rotary machine of *Fig.* 4, the motion of the track is pure rotation, and no inertia forces are set up. Hence the rotary version of

the swashplate mechanism has no dynamic balancing problems, provided the track and rotor are made symmetrical, of course.

For nonrotary machines, *Fig.* 1, in addition to the out-of-balance moment due to the pistons, inertia forces on the track, which has a rather complex motion, must also be considered. This motion is the resultant of the rotation ω of the driving shaft about its axis, and the rotation Ω of the track about an inclined axis fixed to the driving shaft. The acceleration of any point is a result of the composition of the two rotations. Textbooks on advanced dynamics or vector analysis show that accelerations cannot be compounded by simple vector addition of "relative" and "transfer" terms like displacements or velocities. The law of composition of accelerations, or "Theorem of Coriolis," may be stated as follows:

> Let P be a point which is in motion relative to a frame of reference F, and let F rotate at an angular velocity ω relative to a fixed or "absolute" frame of reference. Let Q be a point instantaneously coincident with P but fixed to the frame F, and let a_q be the vector which represents the "absolute" acceleration of Q. If the vectors v' and a' represent respectively the velocity and acceleration of P relative to F, then a, the absolute acceleration of P, is given by
>
> $$a = a' + a_q + 2\,\omega \times v'$$
>
> where the vector product $2\omega \times v'$ is called the "Coriolis acceleration" of P.

In this instance, the frame of reference F is a frame fixed to the driving shaft, and P is a point on the track. The term a' therefore represents the acceleration of a point on the track relative to the track axis —a centripetal acceleration. If the track is symmetrical, forces due to this component obviously cancel out leaving no resultant.

The term a_q is by definition the acceleration which the point P would have if it was fixed to the driving shaft, again a centripetal acceleration. If the driving shaft together with the track are in static and dynamic balance, which can be achieved by regarding the track as fixed to the shaft and balancing accordingly, the resultant forces and moments under this heading will again be zero.

Resultant forces due to the third term (Coriolis acceleration) must now be calculated. For convenience the following axes of reference should be used: OZ coinciding with the track axis; OX perpendicular to both OZ and the shaft axis; and OY perpendicular to OZ and OX. The origin O is at the intersection of the driving shaft and track axes. If Ω is the angular velocity of the track relative to the driving shaft and ω represents the angular velocity of the driving shaft, the product $2\omega \times v'$ is then a vector which has components along OX, OY and OZ given respectively by $2\omega\Omega x \cos \alpha$, $2\omega\Omega y \cos \alpha$ and $2\omega\Omega y \sin \alpha$. These are the components of the Coriolis acceleration of a point P having coordinates x, y, z and lying on the track.

Consider an incremental layer of material parallel to the xy plane (normal to the z axis) and containing the point P. Due to the symmetry of the track all three components of inertia force will have zero resultant moment when summed over the whole layer, since for each point P of coordinates x, y there will be a corresponding point of coordinates $-x$, $-y$, and the forces on the two will cancel out. The first two components, x and y, also produce zero net resultant moment. The third or z-component of force produces no resultant moment about the y axis, but has a net resultant moment about the x axis given by

$$\delta M = \Sigma^{\cdot} - 2\,\omega\,\Omega\,y^2\,\delta m \sin \alpha$$

$$= -\,2\,\omega\,\Omega \sin \alpha\,\delta I_x$$

where $\delta \dot{I}_x$ is the moment of the inertia of the incremental layer about an axis in it parallel to the x axis.

For the whole track the resultant Coriolis moment is given by

$$M_{xc} = -\,2\,\omega\Omega \sin \alpha \int \delta I_x = -\,2\,H\,\omega\,\Omega \sin \alpha$$

where

$$H = \int \delta I_x = \int \rho J_x\,dz$$

The quantity ρ is the density of material and J_x is the second moment (moment of inertia) of the cross-section area of the track about an axis through OZ parallel to OX. Thus, H is the moment of inertia which the track would have about one of its diameters if its mass points were concentrated at a single cross-section perpendicular to the axis.

The moment M_{xc} acts in a sense tending to increase the inclination of the track. It acts about the same axis and in the same sense as the moment M_{xp} due to inertia forces on the pistons. Thus the total out-of-balance moment M_x, is

$$M_x = -\,\frac{N\,m\,\omega^2\,s\,a}{2} - 2\,\omega\Omega\,H \sin \alpha$$

As mentioned previously, $\Omega = \omega \sec \alpha$, at least to a close degree of approximation. The out-of-balance moment then becomes

$$M_x = -\,\omega^2 \left(2\,H \tan \alpha + \frac{N\,m\,s\,a}{2}\right)$$

A rule for balancing may thus be given as: Determine the mass disposition required to give full static and dynamic balance, regarding the track as rigidly fixed to the driving shaft. Then alter the mass disposition so as to give a dynamic out-of-balance moment $-M_x$. Perfect balance will then be obtained.

Summary: A swashplate mechanism in which the pistons bear on a ball-bearing track through spherical heads and are free to rotate within their bores is a favorable arrangement because the relative motion at the point of contact between piston heads and track is pure or almost pure rolling. Wear and friction losses are correspondingly low. Rotary swashplate mechanisms which have a rotating cylinder block are in perfect balance at all times, provided certain quite obvious conditions of symmetry are observed. In nonrotary types out-of-balance forces are caused both by the pistons and by the track. These forces can be readily calculated from expressions developed in this article, and full balance can be obtained by a suitable disposition of the masses on the driving shaft.

POLYDYNE CAM DESIGN - II

Deflections and clearances in cam and follower systems can be anticipated and their effects counteracted in the design of the cam profile. How to approach this essential phase of cam design for high speed and adapt the results to profiles built on polynomial equations are discussed in this article. The final article in this three-part series will demonstrate application of the complete "polydyne" procedure to an actual design.

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A SELECTED cam function is usually applied to only the local interaction of cam and follower. But the mass being displaced at the end of the follower system actually possesses different motion characteristics since the follower system is flexible to some degree and usually not without some slack or clearance. Magnitude of the displaced mass, rate of the spring in spring-return systems, flexibility and mass of the follower linkage—all contribute to the deviation between cam command and end mass response. An example of such deviation is shown in *Fig.* 1.

In many designs, the displacement characteristic of the end mass is of paramount concern for at least two reasons. Often, as in automotive-engine valve-cam systems, adherence to a prescribed motion of the end element (the valve) is essential to proper function of the entire unit. An example in this field is shown in *Fig.* 2. Or, in other applications, dynamic properties of a system are dependent upon what happens to the most massive element of the cam and follower system. Frequently, the most influence is brought to bear by the end element.

The essential feature of the "dyne" phase of the polydyne procedure is to acknowledge this critical difference between command and response. Three principal steps mark this design method:

1. Selection of the desired function to prevail at the end element.
2. Determination of those properties of the follower system that contribute to deviation.
3. Development of an actual cam function that effectively counteracts the "errors" of the follower system and produces the desired motion of the end element.

Such a procedure can be both complex and perhaps far from complete in absorbing all influencing factors. However, certain simplifying measures can be adopted and principal effects can be readily recognized in the computations. The results assume a much greater degree of success than if no attempt is made to account for the system properties. Such modifications in cam profile can conceivably be introduced with any selected mathematical function for the displacement of the end element. However, the procedure is most readily adopted in conjunction with polynomial functions.

System Deviations: The equation for the displacement of the follower (at the cam) must include displacement of the end mass plus three or four additional factors. The following equation, illustrated in *Fig.* 3, embraces most factors likely to be encountered:

$$y_0 = y_c + y + y_d + y_i + y_p$$

where

y_0 = Equivalent cam lift
$= R_l z_0$
y = Actual lift of end element

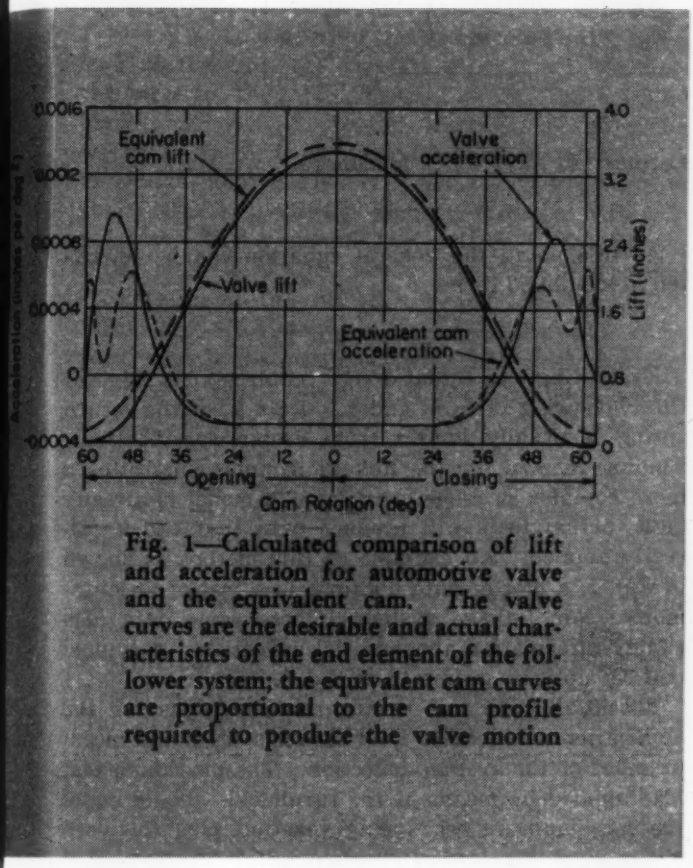


Fig. 1—Calculated comparison of lift and acceleration for automotive valve and the equivalent cam. The valve curves are the desirable and actual characteristics of the end element of the follower system; the equivalent cam curves are proportional to the cam profile required to produce the valve motion

The different symbols for lift might best be first clarified. Actually, z_0 is the lift at the cam proper. Factor R_l represents the mechanical linkage ratio between the cam follower and the end mass. Therefore, $R_l z_0 = y_0$ is the true cam lift referred to the end mass and is termed equivalent cam lift. And y_0 is simply y (the desired lift of the end element) plus adjustment factors derived from the nature of the follower system. These other factors, tabulated in the foregoing discussion, must similarly be referred to the end element.

Clearance and Static Deflection: In actual practice, the most practical means of taking up the clearance y_c and the initial deflection y_p is a ramp—a pre-event subcam whose lift at any point is

$$y_r = y_c + y_p$$

The actual evaluation of the required ramp height, the maximum ramp lift, is one problem; the function to be applied to this subcam and its relationship to the main event constitute a second and more complex problem. Finding ramp height is relatively simple. It is the equivalent static deflection required at the follower to remove all clearance and deflect the follower and spring system to such a point that the end element is on the verge of moving.

If an actual machine is available, ramp height can quickly be determined by actual measurement of the deflection. This procedure is preferable because all deflection components are automatically lumped and need not be determined individually. Deflection of linkage members and their supports must otherwise be calculated or estimated. Standard equations are available for many conditions that might arise. Caution should be observed in calculating deflections, however. Equations usually give results on the "safe" side; that is, calculated deflections are greater than actual deflections. Therefore, no additional allowances should be made as customary in some design practices bearing on deflection studies. Results should be rounded down rather than up. In other circumstances, prototypes of linkage assemblies might be used to obtain data.

Consideration of the ramp contour will be discussed

y_c = Clearance in the system that must be taken up before force is transmitted to the end element

y_p = Initital deflection required to overcome the combined preload of the linkage system and the return spring before any end element lift can occur

y_d = Dynamic deflection of the system, a function of speed

y_i = y-increment deflection, a function of the spring rates of the linkage system and the return spring

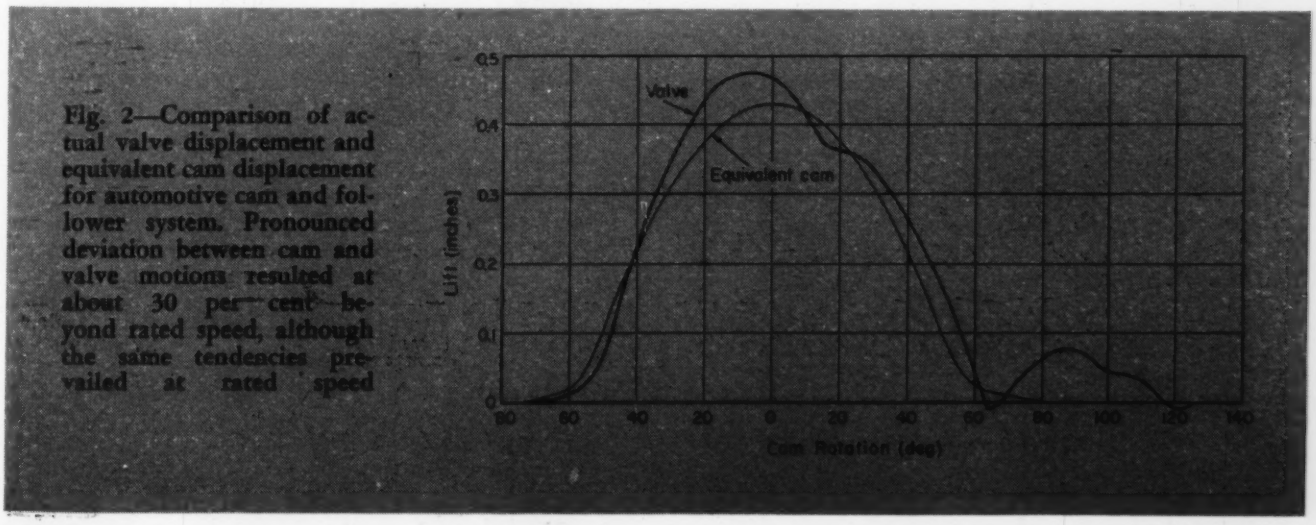


Fig. 2—Comparison of actual valve displacement and equivalent cam displacement for automotive cam and follower system. Pronounced deviation between cam and valve motions resulted at about 30 per cent beyond rated speed, although the same tendencies prevailed at rated speed

in detail in the next article of this series.

Increment Deflection: The y-increment deflection y_i is the deflection of the linkage system caused by the static cam load. That is, as the lift increases, the load imposed by the return spring increases and the linkage deflects an increasing amount. In effect, two springs are at work in the system and may be visualized as a pair operating in a series, *Fig.* 4. The spring rate of the follower train is represented by k_0, the rate of the return spring by k_1. Spring k_0 is forced upward by the cam against spring k_1. The top end of spring k_1 is fixed. Consider the end mass to be connected between the two springs. Then, as the force from the cam compresses both springs, the lower end at the linkage "spring" moves a distance y_s and the end mass moves a distance y. Their difference is the y-increment deflection; that is:

$$y_i = y_s - y$$

If the force applied by the cam is F,

$$y_i = y_s - y = \frac{F}{k_0}$$

But $y_s - y$ is the deflection of the linkage k_0 and

$$F = k_1 y$$

Therefore,

$$y_i = y_s - y = \frac{k_1}{k_0} y$$

Next, y and y_i in the foregoing general equation might be combined. That is,

$$y + y_i = y + \frac{k_1}{k_0} y$$

$$= \frac{k_0 + k_1}{k_0} y$$

Letting $(k_0+k_1)/k_0 = \rho$ leads to

$$y + y_i = \rho y$$

At this point, the general equation can be rewritten in simplified form:

$$y_0 = y_r + \rho y + y_d$$

Evaluating ρ in actual design requires knowledge of the two spring rates k_0 and k_1. Rate k_1 of the return spring is usually known from design specifications. Finding rate k_0 for the linkage system constitutes a more complex problem. Again, if a model is already built, actual tests will produce data that can be directly applied. An example of this method is shown in *Fig.* 5, a plot of data obtained in a test of an automotive cam linkage system. These same data also supply information about initial deflection. A typical test set up is diagrammed in *Fig.* 6.

Essentially the test arrangement provides for the application of a load to the follower system and measurement of the system deflection. The maximum test load applied by means of the turnbuckle should equal the maximum return spring reaction plus the estimated dynamic loading, which will be discussed at length in a later section. During initial testing for automotive-engine cams, the maximum dynamic load is assumed to be two times the maximum spring load for high-speed engines, one and one-half times for lower-speed engines.

Still in reference to automotive cams, the deflection requirement for the ramp on the opening side is de-

Fig. 3—Graphical representation of all components that comprise an equivalent cam contour. Actual lift of the end mass is the major component, but the other factors contribute to the differences shown in the comparisons in *Figs.* 1 and 2

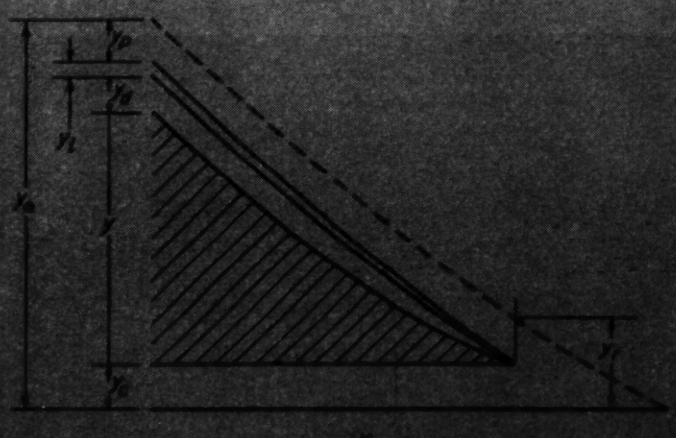
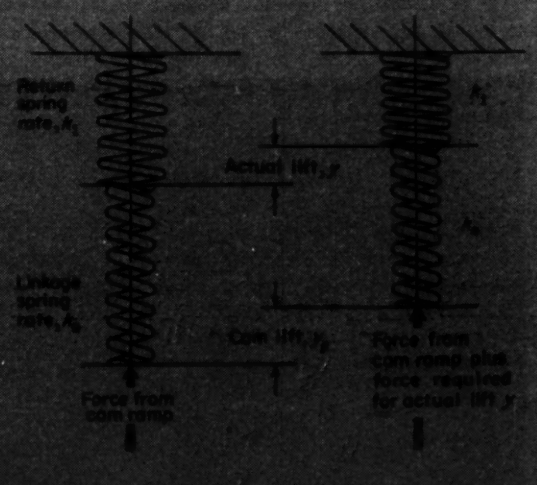


Fig. 4—Return spring and flexible linkage system shown as two springs of rates k_1 and k_0


Return spring rate, k_1
Actual lift, y
Linkage spring rate, k_0
Cam lift, y_s
Force from cam ramp
Force from cam ramp plus force required for actual lift y

termined from the deflection reading at point *B*, *Fig.* 5. The load at this point is the compressed valve spring load at the time the valve is closed. On the valve closing side, the ramp must allow for the deflection reading at point *F*. Static deflection in the system when the tappet is on the cam nose is equal to the deflection at point *C*. When dynamic force is considered, at a certain speed the combined forces will reach point *D*. The maximum acceleration force at design speed plus the static load at the point of maximum acceleration on the cam should equal the load at *D*.

In automotive cam design, a constant value for k_0 may usually be assumed with sufficient accuracy. That is, in *Fig.* 5 the slope of line *EF* would be used: $k_0 = (182-78)/(0.0096-0.0050) = 104/0.0046 =$ 22,600 lb per inch.

The lowest rate is used because one cam (or two at the most) is designed to operate all valves in an engine. Because the proximity of these cams to the cam bearings may vary widely, and other design and material differences may exist, the system spring rates for the different valves are far from consistent. Selection of the lowest slope thus favors adequate compensation for the "weakest" system spring. However, in other applications, a detailed study of the cam system may indicate that a more accurate basis is necessary or at least advisable.

In automotive design, the valve system spring rate is established as a single spring. Actually, it can readily be considered as three separate springs, for there are three sources of maximum deflection:

1. Bending of the cam shaft with load.
2. Compression and bowing of the push rod.
3. Bending of the rocker arm and its shaft plus the stretching of the rocker arm shaft supports.

These factors could be evaluated separately and then combined to establish the value for k_0. Also k_0 could be computed for each separate load condition and then applied over the given range of loading. A new k_0 value could be re-established for each calculated point. Such accuracy is of little value unless the cam is to operate at a constant speed. Such extreme accuracy is still no better than the accuracy of the laboratory data and the accuracy to which the cam can be made.

Dynamic Deflection: In any cam system the dy-

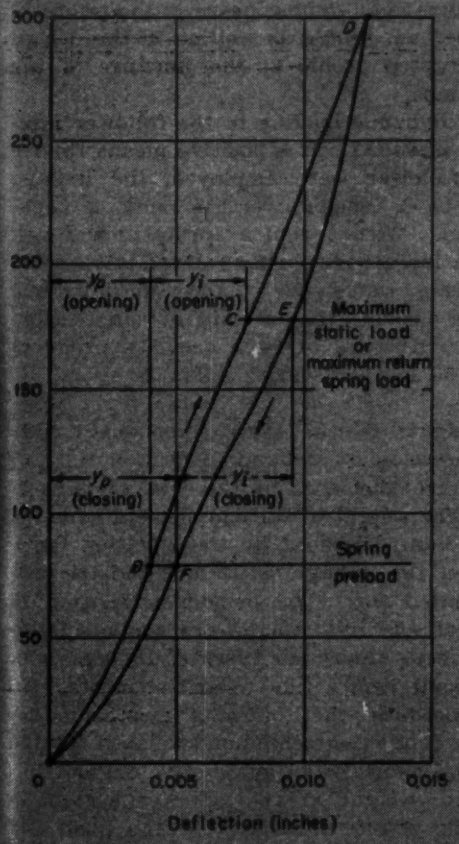


Fig. 5 — "Hysteresis loop" of automotive cam linkage system obtained by test setup shown in *Fig.* 6. Data provide knowledge of required ramp height and of spring rate k_0 of linkage

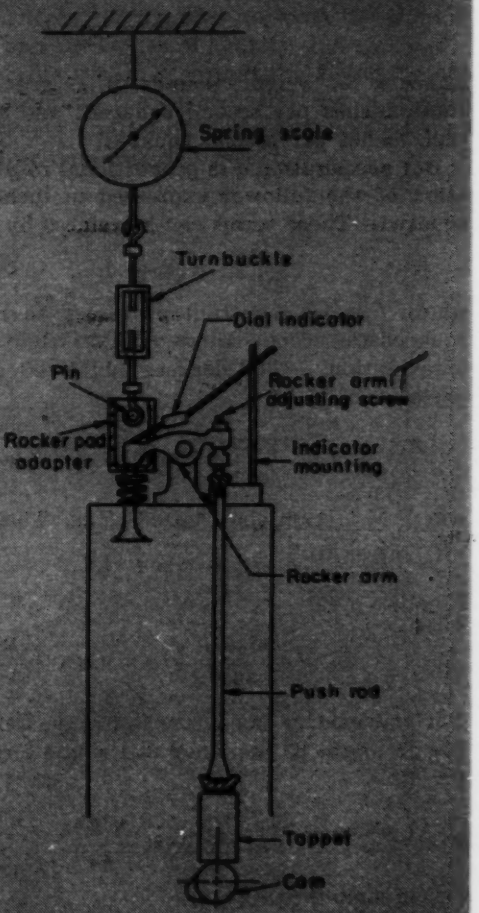


Fig. 6—Test setup for determining the deflection characteristics of automotive cam linkage. Load is applied by means of the turnbuckle; spring scale and dial indicator show load and deflection of system

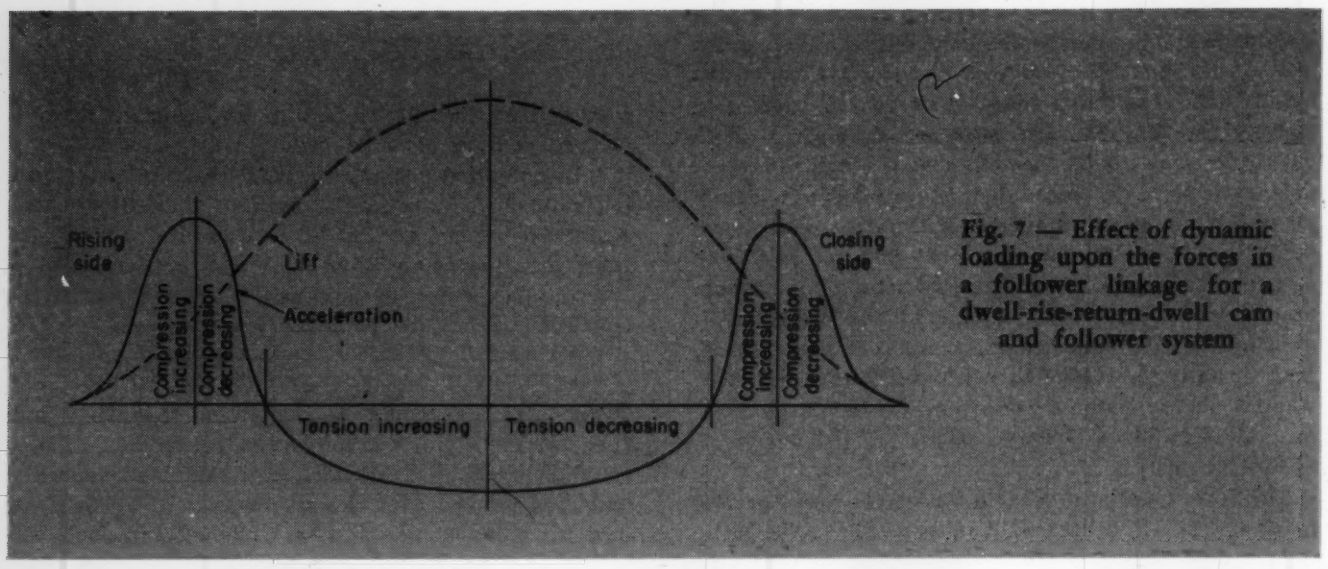


Fig. 7 — Effect of dynamic loading upon the forces in a follower linkage for a dwell-rise-return-dwell cam and follower system

namic deflection y_d is a function of the spring rate k_0 of the system and the force F arising from the acceleration of the system mass. That is,

$$y_d = \frac{F}{k_0}$$

The fundamental relationship for force in this case is

$$F = \frac{w}{g}\,a = \frac{w}{386}\,a$$

where w = weight, pounds, g = gravitational constant, inches per second squared; and a = acceleration, inches per second squared.

But acceleration a is proportional to y'', the acceleration of the follower expressed in inches per degree squared. These terms can be related by

$$a = y''\,f$$

where f is the constant necessary to relate degrees squared to seconds squared. Two basic relationships, 1 revolution = 360 degrees and $N/60$ = revolutions per second, yield

$$f = \left(\frac{360\,N}{60}\right)^2 = 36\,N^2 \text{ deg}^2 \text{ per sec}^2$$

where N = cam shaft speed, rpm. Then

$$a = 36\,N^2\,y''$$

Finally

$$y_d = \frac{36\,w\,N^2\,y''}{386\,k_0} = 0.093\,\frac{w\,N^2\,y''}{k_0}$$

For convenience the terms that have fixed values in a design might be combined in a single term. Therefore let

$$\phi = 0.093\,\frac{w\,N^2}{k_0}$$

Or, in simplified form,

$$y_d = \phi\,y''$$

At this point, the general equation for the cam profile can be restated in its final form:

$$y_0 = y_r + \rho y + \phi\,y''$$

Now the desirability of basic displacement functions (y) whose fourth derivatives are finite becomes evident. Because displacement y_0 of the equivalent cam contains a factor proportional to the acceleration y'' of the end mass, the second derivative of y_0 contains a term proportional to the fourth derivative of y. This feature is of some concern in the practical execution of the cam profile as well as in the design for an uninterrupted profile at the juncture of the cam with its ramps.

The effect of dynamic loading in the follower linkage is depicted in *Fig.* 7. If a positive means for restraining the follower were employed, the linkage would actually be in tension over the range of negative acceleration. With a return spring in the system at the location conventional in automotive valve trains, the spring would overbalance the dynamic tensile load and provide the security of compression in the linkage. Absence of such security produces malfunctioning of the sort shown in *Fig.* 2.

Effective Weight: Of the three components comprising the expression for dynamic deflection, only w, the weight of parts displaced by the cam, remains to be discussed. The weight of the end element which is to have the motion described by the equation for y and a portion of the linkage between it and the cam must be accounted for. The principles relating to determination of effective weight are common with minor variations to almost all types of linkages employed to transmit cam action to end elements. To outline the procedure, the following discussion describes in some detail the technique developed for the over-head valve linkage of an automotive engine.

Total effective weight at the follower system is made up of the effective weights of the push rod (w_{ep}), the rocker arm (w_{er}), and the valve unit (w_{ev}). As will be shown, certain of these effective weights are the actual weights of components, others are not.

In earlier discussion, three sources of deflection in

the linkage were listed. Each might have been analyzed separately, and these individual deflections totaled. For simplicity, however, total deflection for the system is assumed to occur in one member—the push rod. Hence, the push rod is assumed to be a spring of rate k_0 acting between the cam and the end element of an equivalent or effective weight w.

Since the cam itself and the tappet are on the action side of spring k_0, they do not affect the weight moved on the reaction side. However, the push rod (the assumed spring) moves some part of its own weight. One-third is the fraction commonly employed in this type of design. The effectiveness of this one-third spring weight must be transferred to the end element, the valve, and added to the effective weight of the valve.

The intermediate link, the rocker arm, generally multiplies the cam lift at the valve by a ratio of R_l. Located on the slower moving side of the rocker arm, the push rod applies less mass effect against the reaction side of the spring.

Since the mass is in motion, the transfer of its effectiveness involves a consideration of kinetic energy. The kinetic energy of the push rod is (*Fig.* 8)

$$E = \frac{1}{2}\,\frac{w_p}{3\,g}\,v_p^2$$

where w_p = actual push rod weight, v_p = push rod velocity, and the factor of 3 accounts for the assumption that only one-third of the push rod weight is effective.

The corresponding and equal kinetic energy on the valve side of the rocker arm must be

$$E = \frac{1}{2}\,\frac{w_{ep}}{g}\,v_v^2$$

Since these two energy expressions can be equated,

$$w_{ep}\,v_v^2 = \frac{w_p}{3}\,v_p^2$$

or

$$w_{ep} = \frac{w_p}{3}\left(\frac{v_p}{v_v}\right)^2 = \frac{w_p}{3\,R_l^2}$$

where by definition the mechanical linkage ratio $R_l = v_v/v_p = r_v/r_p$.

Next, the effective rocker arm weight w_{er} must be determined. The method commonly employed is to derive the effective weight from the moment of inertia which is ascertained by the treatment of the rocker arm as a compound pendulum. Usually the rocker arm is suspended on an axis located close to the valve stem contact surface, parallel to the rocker shaft hole. The point of oscillation is O in *Fig.* 8. The arm is allowed to freely oscillate and the frequency, f, is determined in cycles per second. Then, the moment of inertia of the rocker arm about the point of oscillation is

$$I_O = \frac{w_r\,d}{4\,\pi^2\,f^2}$$

where d in inches is the distance between the point of oscillation O and the center of gravity G.

Location of the center of gravity is found by balancing or suspending the rocker arm from a number of different points and locating the common intersection of the different axes of support.

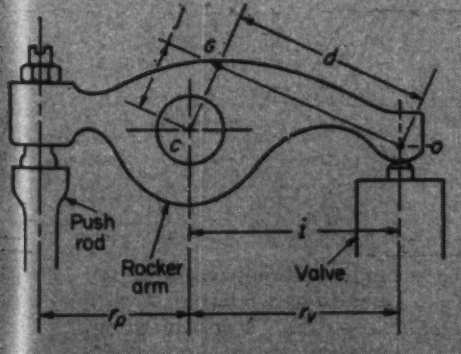


Fig. 8—Above—Diagram showing properties essential in the computation of effective weight of parts in an automotive cam linkage system

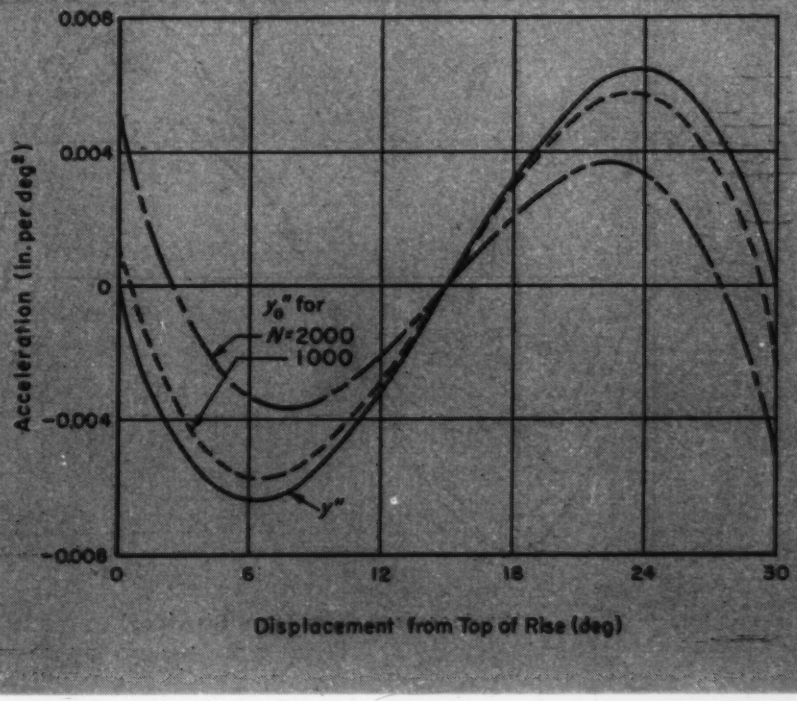


Fig. 9—Right — Comparison of equivalent cam acceleration y_0'' at different cam shaft speeds with acceleration y'' of end mass for 3-4-5 polynomial

The moment of inertia at the center of gravity is

$$I_G = I_O - \frac{w_r d^2}{g}$$

where g = gravitational constant = 386 inches per second squared. Next, at the center of rotation C, the moment of inertia is

$$I_C = I_G + \frac{w_r j^2}{g}$$

But I_C may also be written as though the effective weight of the rocker arm (w_{er}) were concentrated at a distance i from the center of rotation. Distance i is measured perpendicular to the vertical valve axis.

$$I_C = \frac{w_{er} i^2}{g}$$

Or finally

$$w_{er} = \frac{386\, I_C}{i^2}$$

$$= \frac{w_r}{i^2}\left(\frac{386\, d}{4\,\pi^2 f^2} - d^2 + j^2\right)$$

Usually, for automotive cam rocker arms this procedure shows that $w_{er} = w_r/3$ or that $w_{er} = w_r R_1/5$.

The effective weight of the valve unit w_{ev} must account for the weight of the valve itself, its keepers, the valve spring, and the spring retainers. These parts comprise the end element; therefore, their actual weights comprise the effective weight with the exception of the valve spring. Just as in the case of the push rod, only one-third of the valve spring weight is assumed to contribute to the inertia loading. Or, if w_v represents the actual weight of all valve unit components including the valve spring and w_s the actual total weight of the spring.

$$w_{ev} = w_v - \frac{2\, w_s}{3}$$

The final effective weight for this analysis of an automotive cam system is then

$$w = w_{ep} + w_{er} + w_{ev}$$

Influence of Variables: A recapitulation of the relationship involved in the dynamic action of cam and follower systems shows that

$$y_0 = y_r + \rho\, y + \phi\, y''$$

where y_0 is displacement of the equivalent cam required to produce displacement y at the end element, y_r is the ramp height,

$$\rho = \frac{k_0 + k_1}{k_0}$$

and

$$\phi = 0.093\,\frac{w\, N^2}{k_0}$$

In most designs, certain of the terms are constants or may be so considered. For example, the spring rates k_0 and k_1, the effective weight w, and perhaps the rotational speed N are usually constant. If they are not, specific values hold for them, at least for a given point or through a given range. Any change that may occur in them, such as by the addition of weight or change in rotational speed during a cycle must not be introduced instantaneously. Although instant or rapid changes might be anticipated in the design, they would be reflected by steps on the profile

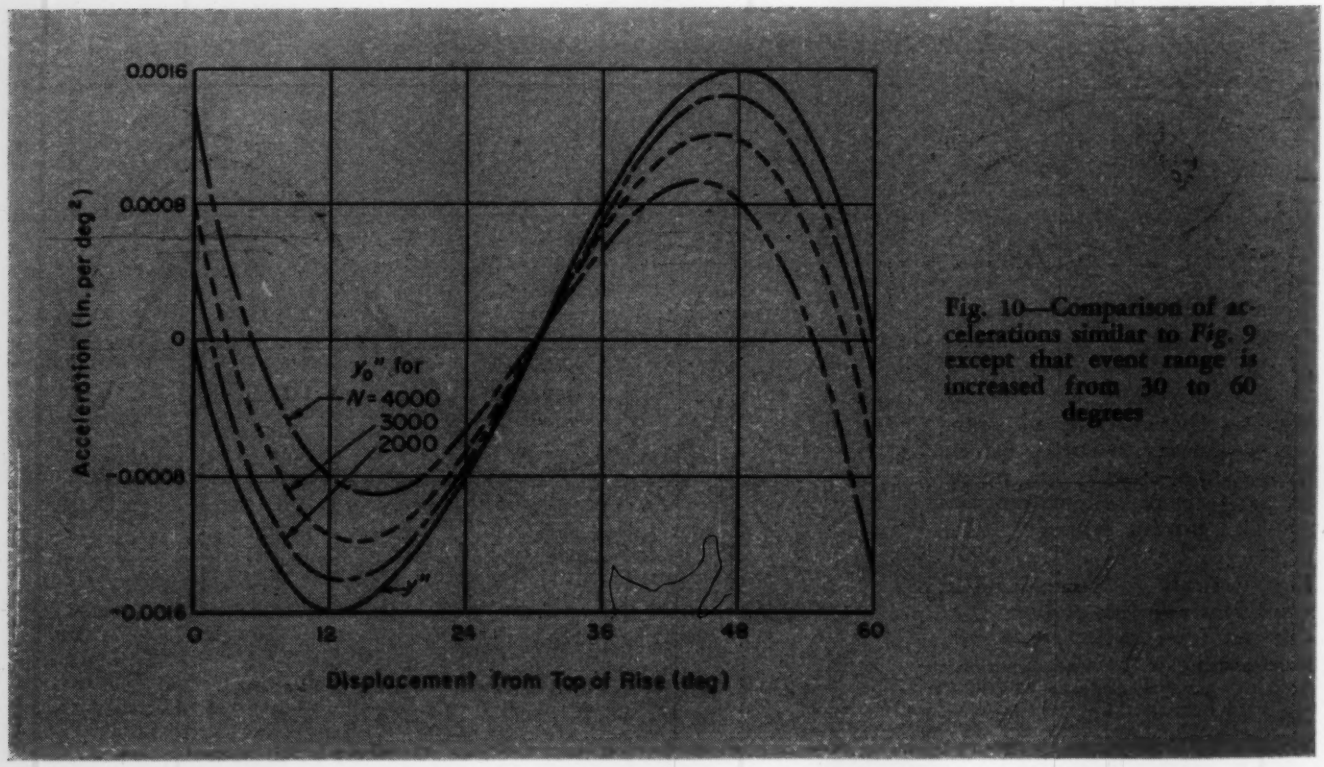


Fig. 10—Comparison of accelerations similar to *Fig. 9* except that event range is increased from 30 to 60 degrees

and practical execution of the cam would be impossible or impractical.

Velocity and acceleration at the equivalent cam are derived by differentiation of the displacement equation:

$$y_0' = \rho\, y' + \phi\, y'''$$

$$y_0'' = \rho\, y'' + \phi\, y^{iv}$$

What these equations mean in contrast to the basic polynomials discussed in the first article of this series can be demonstrated by several simple examples. Let the conditions of a particular design be: range over which the lift occurs, $x_r = 30$ deg; total lift $C_0 = y_{max} = 1$ inch; system spring rate, $k_0 = 31{,}000$ lb per inch; return spring rate, $k_1 = 310$ lb per inch; and effective weight of the follower system, $w = 1$ lb.

Then, $\rho = (31{,}000 + 310)/31{,}000 = 1.01$ and $\phi = (0.093)(1)N^2/31{,}000 = 0.000003\ N^2$. Cam shaft speed N will be introduced later.

Next, a profile is selected. First, the basic 3-4-5 polynomial derived in the earlier article will be tried. Displacement of this profile is

$$y = 1 - 10x^3 + 15x^4 - 6x^5$$

in the "unitary" system wherein displacement of one unit of distance is assumed to occur in one unit of time. Converting this expression so that the actual units of a particular design prevail is accomplished by alteration of the coefficients.

Such conversion is simply handled. If any term of the "unitary" equation is Cx^n, converted to the actual design conditions it is simply $y_{max}Cx^n/x_r^n$. That is, each term of the equation is multiplied by the total actual lift y_{max} of the end element and divided by the lift range x_r raised to the same power as x.

For this example, $y_{max} = 1$ inch and $x_r = 30$ deg. Therefore, at the end element

$$y = 1 - 10\left(\frac{x}{30}\right)^3 + 15\left(\frac{x}{30}\right)^4 - 6\left(\frac{x}{30}\right)^5 \text{ inches}$$

Velocity at the end element is

$$y' = -\frac{(10)(3)}{30}\left(\frac{x}{30}\right)^2 + \frac{(15)(4)}{30}\left(\frac{x}{30}\right)^3 - \frac{(6)(5)}{30}\left(\frac{x}{30}\right)^4$$

$$= -\left(\frac{x}{30}\right)^2 + 2\left(\frac{x}{30}\right)^3 - \left(\frac{x}{30}\right)^4$$

Similarly, acceleration, jerk, and the fourth derivative are

$$y'' = -\frac{1}{15}\left(\frac{x}{30}\right) + \frac{1}{5}\left(\frac{x}{30}\right)^2 - \frac{2}{15}\left(\frac{x}{30}\right)^3$$

$$y''' = -\frac{1}{450} + \frac{1}{75}\left(\frac{x}{30}\right) - \frac{1}{75}\left(\frac{x}{30}\right)^2$$

$$y^{iv} = \frac{1}{2250} - \frac{1}{1125}\left(\frac{x}{30}\right)$$

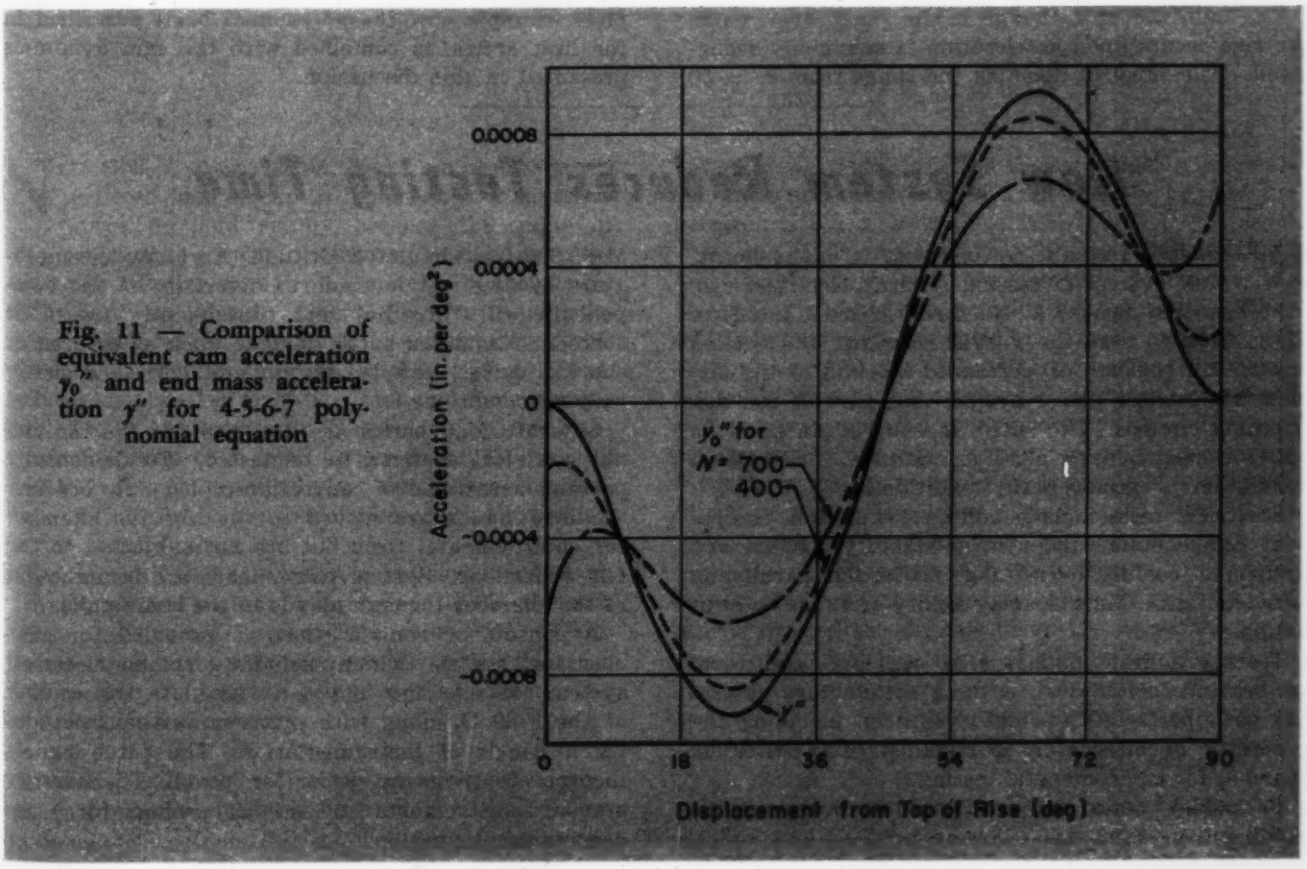


Fig. 11 — Comparison of equivalent cam acceleration y_0'' and end mass acceleration y'' for 4-5-6-7 polynomial equation

CAM DESIGN

Units of velocity, acceleration, etc., are inches per deg, inches per deg^2, etc.

Particularly appropriate in revealing the effects of the system properties is the acceleration of the equivalent cam. Then,

$$y_0'' = \rho\, y'' + \phi\, y^{iv}$$
$$= 1.01\, y'' + 0.000003\, N^2\, y^{iv} \text{ inches per deg}^2$$

where y'' and y^{iv} are given by the immediately foregoing equations. Different design speeds might be tried. For $N = 1000$ rpm,

$$y_0'' = 1.01\, y'' + 3\, y^{iv}$$

For $N = 2000$ rpm,

$$y_0'' = 1.01\, y'' + 12\, y^{iv}$$

Calculated points for the acceleration y'' of the end element and the acceleration y_0'' of the equivalent cam for $N = 1000$ and 2000 rpm yield the curves shown in *Fig.* 9.

Increasing difference between end-mass acceleration and acceleration at the cam with increase in rotational speed N is effectively shown in *Fig.* 9. A similar trend would be evident if other system properties were also altered. That is, departure of acceleration from zero at the event terminals will increase with higher effective weight w and lower system spring rate k_0. These latter two properties bear linearly upon the results whereas the square of speed is effective. If design speed were zero or near zero, y_0'' would approach 1.01 y''. Only the spring properties create a difference which in this example is 1 per cent.

The influence of a change in the range over which the rise occurs upon acceleration is commonly recognized. The effect of doubling the range from $x_r = 30$ deg to $x_r = 60$ deg is shown by comparison of *Figs.* 9 and 10. For the 60-deg range of *Fig.* 10, departure of cam acceleration y_0'' from zero at the event terminals is the same at $N = 4000$ rpm as the departure for $x_r = 30$ deg at $N = 2000$ rpm.

An interesting and practical point accented by *Figs.* 9 and 10 is that the event begins and ends with a finite acceleration, and therefore there is infinity jerk at the contact of cam and follower. This feature suggests another required function of ramps (pre and post-event subcams). Besides taking up the clearance and preload in the system, the ramps should also provide follower acceleration of values required at the true initiation and termination of the event. This subject will be discussed in more detail in the final article of this series.

Another example showing the difference between y'' and y_0'' is given by *Fig.* 11, for which the basic polynomial is

$$y = 1 - 35\, x^4 + 85\, x^5 - 70\, x^6 + 20\, x^7$$

In this case, since jerk is zero at the terminals of the event, a different character is imparted to the equivalent cam acceleration curves near the terminals.

A perception of benefits to be gained through accommodation of system properties in the cam design is given by a comparison of the curves in *Figs.* 9 to 11 if an inverted point of view is taken. That is, in conventional design the maximum acceleration at the cam, which is also usually assumed to prevail at the end mass, would be the peak of any one of the y_0'' curves. But the true acceleration at the end mass, considerably greater than at the cam, is indicated by the corresponding ordinate on the y'' curve.

The final article of this series will show by a complete example how the polynomial basis described in the first article is combined with the cam dynamics presented in this discussion.

New System Reduces Testing Time

REDUCING in-flight testing time by many hours, a new system of testing aircraft electrical systems has been devised at Northrop Aircraft Inc. Now being used to test the F-89D Scorpion, the testing mechanism consists of a detailed mockup of the airplane's electrical power system and part of the distribution circuits. The entire mockup is placed in an extreme temperature altitude chamber for realistic simulation of atmospheric conditions.

Electrical tests include voltage regulation, component compatibility and system stability, system and component cooling, overvoltage protection, paralleling characteristics, fault clearing ability and fuse co-ordination.

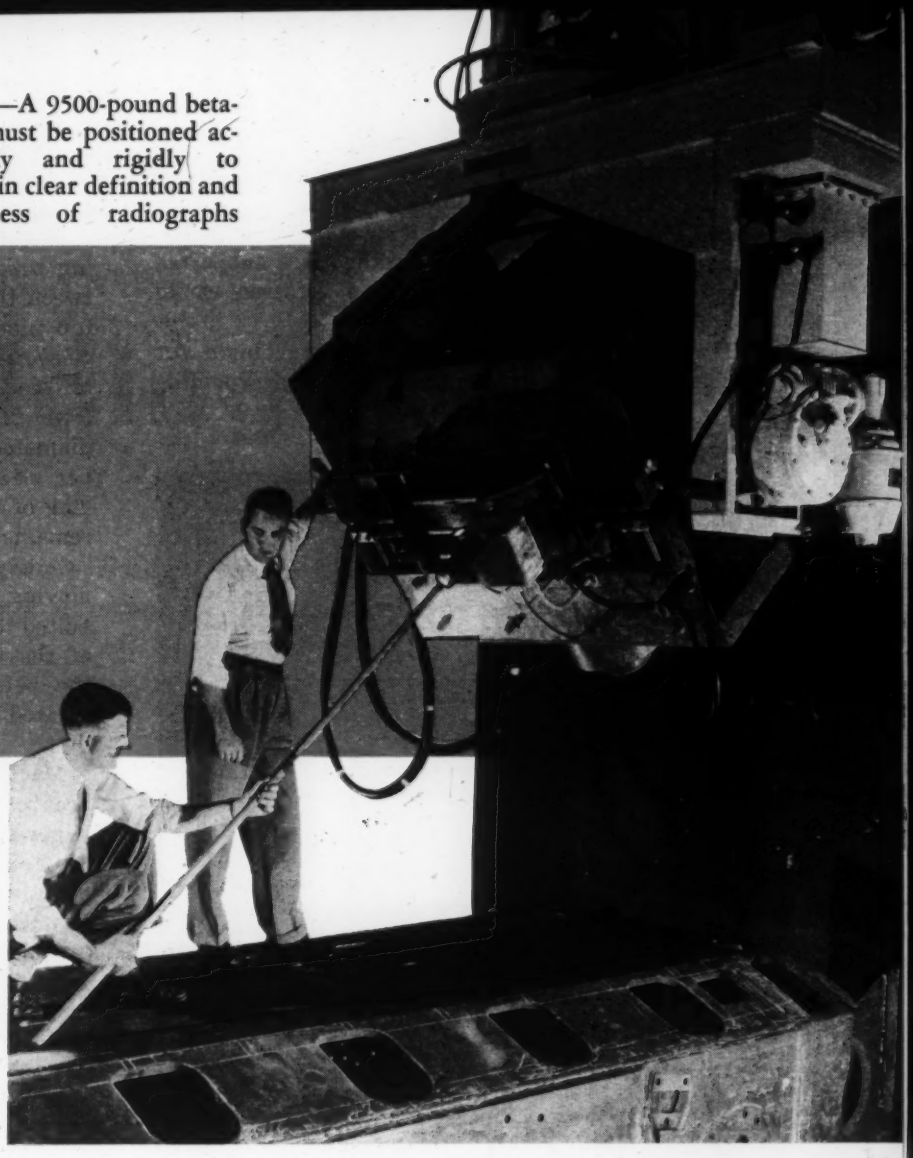
Tests are first conducted at sea level and room temperature conditions. After a satisfactory system has been perfected, the entire system, including the generator or alternator, is installed in the altitude chamber for environmental testing.

Secondary tests are conducted at temperatures varying from 160 F to −65 F at sea level and −65 F at 50,000 feet simulated altitude. An altitude-temperature cycling test is made to determine if the components will "breathe" and consequently freeze or corrode. Simulated battle damage, such as severed or shorted cables, can be set up and corrected under varying conditions.

Separate load banks are designed for the individual electrical systems to be tested. Fundamentally portable assemblies of convection-cooled strip heaters, the load banks are moved to the altitude chamber for environmental tests but are not subjected to the test conditions. System power leads are brought out of the chamber through glands to the load banks.

A console or control bench is provided for each electrical system, which includes airplane electrical system controls and meters to simulate the cockpit of the F-89 D, along with prime mover controls and patch panels of instrumentation. The patch panels incorporate plugs or jacks for portable laboratory standard instruments and duplicate plugs for a recording oscillograph.

Fig. 1—A 9500-pound betatron must be positioned accurately and rigidly to maintain clear definition and sharpness of radiographs



TELESCOPING TUBES

. . . a unique answer to betatron support problems

By Robert J. Stamp
Allis-Chalmers Mfg. Co.
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NOT ONLY is a betatron, *Fig.* 1, an unwieldy and delicate instrument to handle, but it must always be held rigidly because the value of radiographs made with a betatron depends on clear definition. Radiographs are merely photographic shadows of an object. The degree to which the source of X-rays can be reduced to a stationary point, therefore, determines the radiograph sharpness. Thus, mechanical vibration must be eliminated during exposure. The X-ray source or "focal spot" in the betatron is a portion of a small target only 0.010-inch by 0.005-inch in size, practically a point source of radiation. If this can be kept stationary during exposure, a sharp picture is assured.

For convenience, the betatron is suspended from a traveling crane so that it can be spotted in the best position relative to the part being inspected. While this overhead mounting releases the entire floor for working area, it presents problems that exercise the design engineer's talents.

Mounting Design: The mechanism designed to support and maneuver the betatron can be divided into five separate sections, *Fig.* 2, each having independent motion. These are the crane bridge, crane trolley, telescope tube assembly, mounting yoke, and the betatron itself.

As the main means of maintaining rigidity of the betatron, the telescope tube assembly is mounted on the trolley and consists principally of four steel tubes which telescope into each other. These tubes do not support the weight of the betatron because the hoisting cable extends down through the tubes and passes over sheaves mounted in the bottom tube. The suspension-saddle assembly, which contains a gearmotor for rotating the yoke assembly, is attached to the lower end of the bottom tube.

The yoke assembly rotates 350 degrees about the vertical axis coinciding with the centerline of the telescope tubes, and the betatron mounted in this yoke can be rotated 180 degrees about the horizontal axis. The focal spot is positioned at the intersection of the horizontal and vertical axes of rotation. Thus the position of the focal spot does not change with rotation of the betatron about either axis.

Why a Telescope?: The most unique and interesting part of the whole mechanical structure is the tele-

scoping tube section of the mounting. A means had to be found to support the betatron rigidly enough so that oscillation and vibration would not cause blurred radiographs, equipment damage and inconvenience. Obviously, if the machine were supported merely by cables from a crane, the betatron would swing like a pendulum.

Among the advantages of a tubular column for betatron support are: symmetrical rigidity, providing equal strength against forces from all directions; telescoping simplicity, providing an economical means for smooth vertical adjustment; and weight economy.

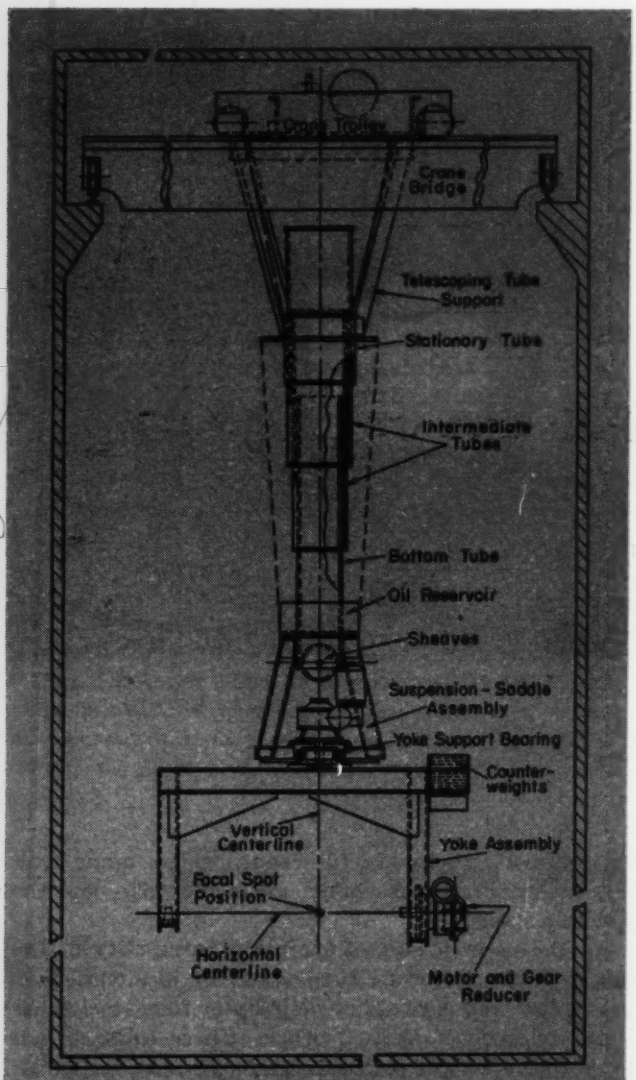
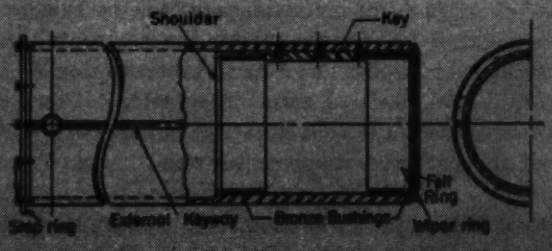


Fig. 2—Above—Four tubes make up the telescoping tube assembly

Fig. 3—Below—A long external keyway, mating with an internal key on the next larger tube, prevents angular oscillation



In the current design of the telescope, the telescoping tube support forms a fairly rigid connection between the top tube and the crane trolley frame. The top tube is short, only as long as the 22-inch bronze sleeve section it contains. The two intermediate tubes are each 80 inches long, with bronze sleeves in the lower 21 inches of their length, *Fig.* 3. The inside diameter of each tube is relieved at the top of the upper sleeve to provide a shoulder on which the stop ring of the next smaller tube rests. Thus each sleeve remains fully engaged at all times.

A keyway is cut in the outside of each of the three moving tubes along its entire length, matching a key bolted to the inside of the mating tube. Thus twisting of the telescope assembly and angular oscillation of the betatron is prevented and the betatron can be rotated by the motor in the suspension-saddle assembly.

Machined from solid steel forgings, the tubes have bronze sleeves pressed in and center-bored. Special wiper rings, bolted to the bottom of each of the three top tubes, aid in oil distribution. These wiper rings contain rings of felt which, when saturated with oil, keep the steel tubes lubricated. Oil running down the outside of a tube is guided to the outer surface of the next tube by channels in the wiper rings to prevent dripping. All oil drains into a reservoir at the bottom of the lower tube. As the betatron is raised, the end of each intermediate tube is successively immersed in this reservoir. The bottom plate of the reservoir then supports these tubes.

When not in use, the betatron is designed to be stored in a position of maximum elevation. All felts then become saturated with oil for subsequent operation. The space above the top stationary tube is enclosed by a Neoprene bag, so that storage of the betatron at maximum elevation places all tubes within this bag to keep dust from settling on the steel surfaces.

Flexibility versus Rigidity: Although the telescope proves adequately rigid, it is certainly not perfectly so. Assuming a fully extended telescope with perfectly rigid sleeve joints (virtually a solid one-piece tube), there would still be considerable pendulum action. The 9500-pound betatron would swing freely at the end of a 29-foot cantilever beam with an amplitude of an inch or more upon starting and stopping of the crane bridge or trolley.

Considering that this pendulum actually has three sleeve joints, each with several thousandths inch play, there appears to be even more allowance for oscillation and the probability of a greater amplitude. However, in practice, friction in each joint is an excellent damping force on any oscillations built up in the telescope, and the betatron reaches an equilibrium position faster with the jointed telescope than if only one rigid tube were employed, even though initial deflection may be greater. The telescope assembly provides a mounting rigid enough to insure a stationary betatron during exposures, yet flexible enough to isolate and damp vibrations.

Designing for Spotwelding

PRODUCTION AND DESIGN

Basic design standards for engineering efficient spotwelded assemblies from both strength and economy standpoints

WHEN designing a unit for fabrication by spotwelding, the primary design consideration must be the stress imposed upon the unit. A spotweld develops its full strength only when subjected to shear loads; only approximately 25 per cent of its shear strength is developed when subjected to a tension load. If the stress criteria is less than 80 per cent shear, a riveted or bolted connection should be used. In many cases, however, it is possible to use a combination of spotwelds and tack-rivets without sacrificing the advantages of spotwelding.

Production Economics: Due to excessive handling and set-up time, large assemblies where the majority of the unit is riveted are not recommended for spotwelding unless 25 or more spots may be used. Small subassemblies, or unit parts requiring a few spots, may be economically fabricated if the volume of work

Based on data supplied by the Ryan Aeronautical Co., San Diego, Calif.

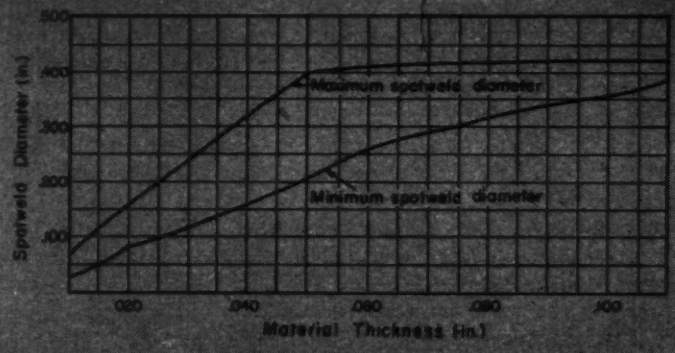
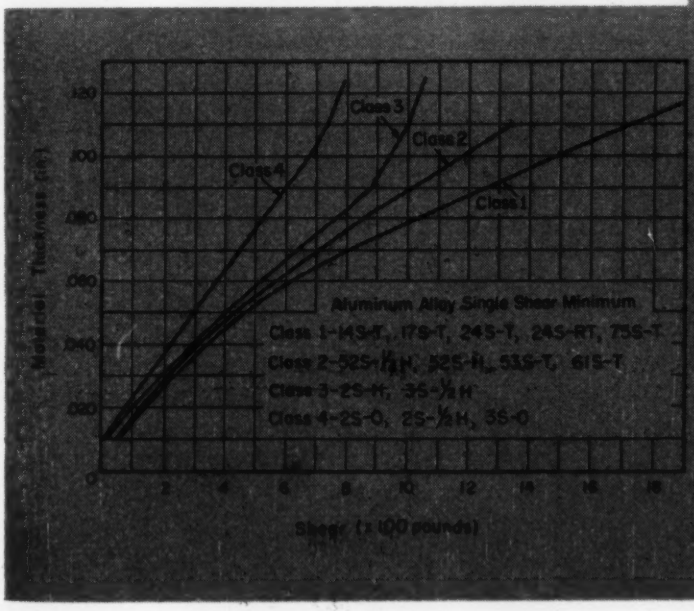


Fig. 1—Range of spotweld diameters required to develop full shear strength



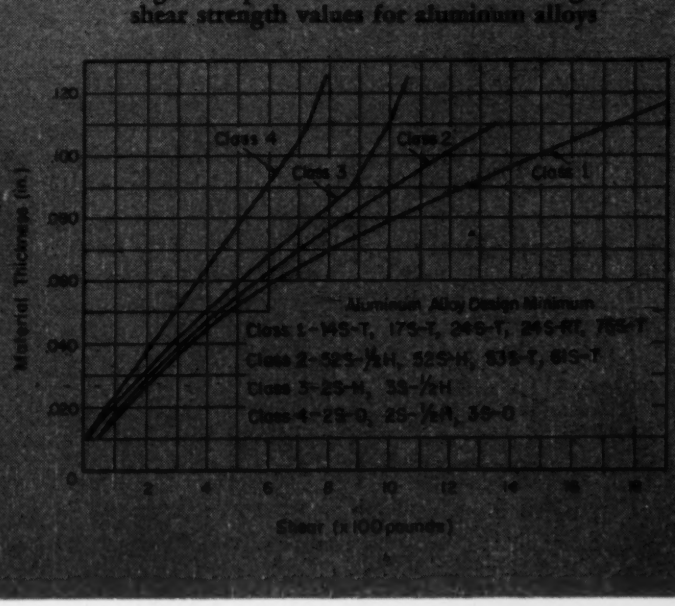


Fig. 2—Spotweld minimum and design shear strength values for aluminum alloys

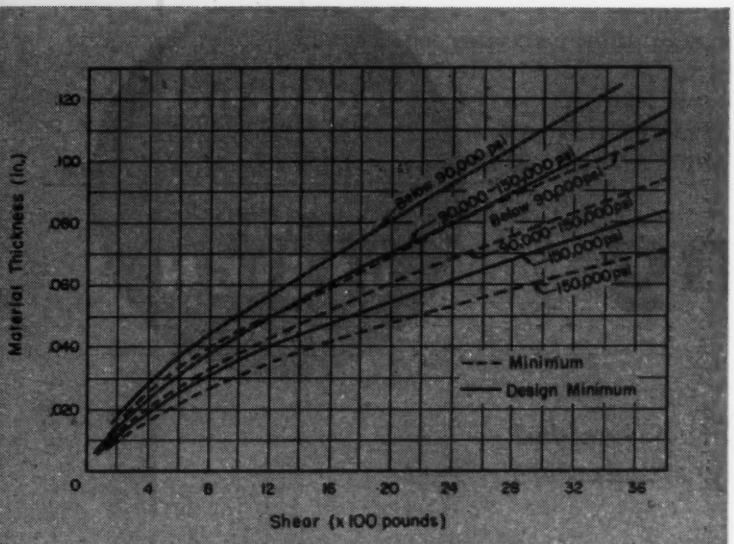


Fig. 3 — Spotweld minimum and design shear strength values for steel

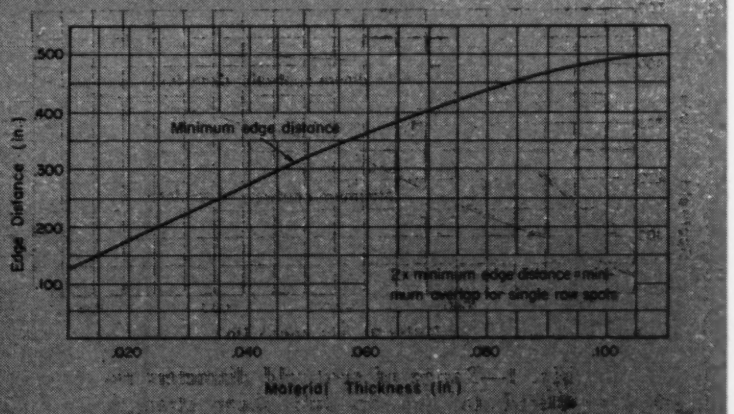


Fig. 4 — Minimum edge distance necessary for full strength welds

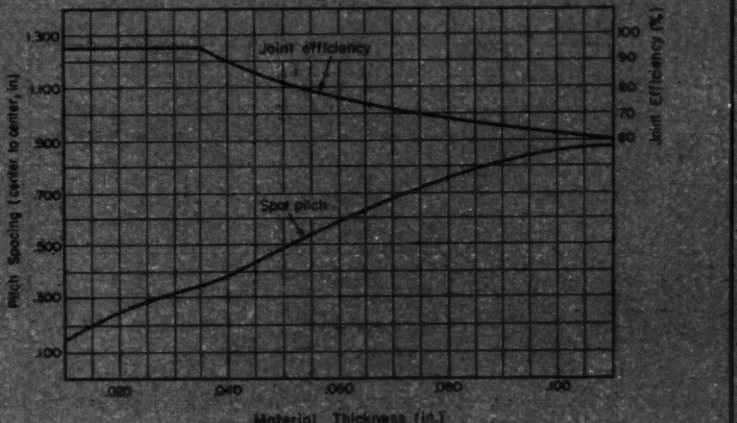


Fig. 5 — Spotweld pitch and joint efficiencies for single-row spots

is high enough. However, spotwelding is most economical when a production rate of 35 to 120 spots per minute can be used. *Clean, accessible design* is the major factor governing the production economy of spotwelding.

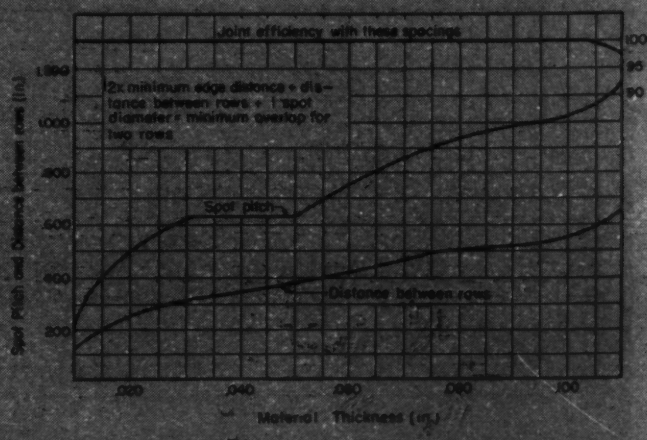
Material Gage: As the material thickness to be welded increases, more heat is required to form the weld. When the sheets are of equal thickness, the weld penetration into each sheet is equal, but when one sheet is thicker, the penetration will be greater in the thick sheet. This unbalanced weld effect continues as the thickness ratio of the thinnest sheet to the total joint thickness increases, until the practical limit is reached at 3½ to 1 with the thinnest sheet considered as 1. Thus, if the thinnest sheet is 0.050-inch, the maximum joint thickness that should be spotwelded is 0.175-inch.

Use of projection welds will, in many cases, permit the spotwelding of parts whose metal thickness ratio exceeds 3½ to 1. In any event projection welding should be considered when the metal thickness ratio exceeds 2 to 1.

Metals composed of different elements will have different electrical resistance. When two metals of the same thickness but of different material composition are spotwelded, the metal having the higher resistance will produce the larger cast metal area, and the metal of lower resistance will produce the smaller cast metal area. This is caused by the fact that the higher the resistance, the more heat developed and consequently the larger the cast area produced.

The preceding conditions make an unbalanced spotweld which from the structural standpoint is unsatisfactory and must be taken into account when designing spotwelded assemblies. For example, metals of different composition but of the same basic

Fig. 6—Spotweld pitch and distance between rows for two and three-row spots



material may be satisfactorily welded if the difference in electrical resistance of the metals is compensated for by increasing the thickness of the metal having the lower resistance. This will produce a balanced spotweld. For all practical purposes it may be assumed that the electrical resistance is directly proportional to the metal thickness.

Where design conditions will not permit the increasing of electrical resistance by increasing the metal thickness, a balanced spotweld may be obtained mechanically by using special size electrodes. This practice is recommended only under unusual design conditions.

Strength of Welds: Shear strength of a spotweld is dependent upon its diameter, and the diameter is a function of the material thickness. For example, it may be seen from *Fig.* 1 that a spotweld diameter that will develop full shear strength for a material gage of 0.040-inch may have a minimum diameter of 0.160-inch or a maximum diameter of 0.320-inch.

Spotweld diameters less than minimum will not have the cross-sectional area necessary to meet the minimum shear strength for a structural spotweld, also, spots below minimum diameter may result in welds lacking the 20 per cent minimum penetration required. In contrast, however, diameters exceeding the maximum usually have large cast areas (which have low per cent elongation properties) and excessive penetration to the extent that the stress loads are not carried over and around the cast structure but are, in effect, abruptly stopped, causing extreme stress concentrations at the edges of the cast structure. This defeats the purpose of designing for high joint strength with the material being used.

Shear strength is a direct function of spot diameter and does not vary with material thickness. However, the practical limits wherein this applies are when the spot diameter is smaller than standard for a particular material thickness and when the difference between the material thickness used in determining the spot diameter and the actual material thickness is not less than 0.004-inch. The graphs in *Figs.* 2 and 3 give spotweld shear strength values for steel and commonly used aluminum alloys as: (1) Army-Navy minimum shear values; and (2) design shear values.

The AN minimum shear values are the minimum values which must be produced by the spotwelding machine. When the shear value of a spotweld falls below this minimum, the machine is reset so that above minimum shear value will be maintained on all spotwelds. The design minimum shear values are the engineering values to be used in determining spotweld shear strength when designing spotwelded assemblies. These values are 80 per cent of the Army-Navy minimum shear values. Designs using different material thicknesses should be based on the shear value for the thinnest material in the joint. Engineering drawings should specify the minimum shear strength required. This minimum value is for one spot only.

Edge Distance: This is the distance from the center of the spot to the edge of the material. Correct edge distance is required for two reasons: (1) To allow adequate space for electrodes to apply pressure around the entire area where the spotweld is to be formed; and (2) to leave sufficient wrought material around the cast structure of the weld to carry the stresses. The minimum edge distance and the amount of overlap required is shown in Fig. 4. These values will apply only when standard size spotwelds as indicated in *Fig.* 1 are used.

Designs allowing sufficient edge distance for spotwelding may be trimmed to the edge of the spotweld after assembly, providing the part is lightly stressed in a shear load only. Trimming to the edge of a spotweld row decreases the area of wrought material necessary to carry the stresses around and over the cast spot structure of the spotweld and thereby reduces the shear value of the joint.

Weld Spacings: Spotweld pitch—the distance between adjacent spotwelds measured from center to center of spots—is important when the strength requirements of a design are high and it is necessary to place a quantity of spotwelds in a comparatively small area. Minimum pitch should not be less than the pitch specified in *Figs.* 5 or 6. If the spotweld joint is comprised of unequal thickness of material, the lesser material gage is used in determining the correct pitch.

If strength requirements for a design are low and the available area for spotwelding is large, the minimum pitch specified may be disregarded and a relatively large pitch employed. Designs using large spotweld pitch must be carefully analyzed. If the pitch is too great, the spotwelds may have localized stresses applied which will tend to overload individual spots causing their failure. To avoid overloading individual spots, the spotweld pitch and joint efficiency curves in *Figs.* 5 and 6 should be consulted in determining the proper spotweld spacing.

Joint Efficiency: It will be noted that joint efficiency for a single-row spot pattern decreases rapidly as the material gage exceeds 0.035-inch. This is attributed to the fact that the tensile strength of the material increases more than does the shear strength of the spotweld resulting in a decreased joint efficiency. To overcome this condition and maintain high joint efficiency it is necessary to resort to a two or three-row spot pattern. When a two or three-row spot pattern is used, the joint is stronger than the parent metal, *Fig.* 6, hence 100 per cent joint efficiency is obtained.

"How many newspaper readers can identify the designer of the George Washington Bridge or the Empire State Building, the inventor of color television or the electric dishwasher? To attract capable young men to engineering, industry must call attention to the man, as well as the product."—DR. J. H. DAVIS, *president, Stevens Institute of Technology.*

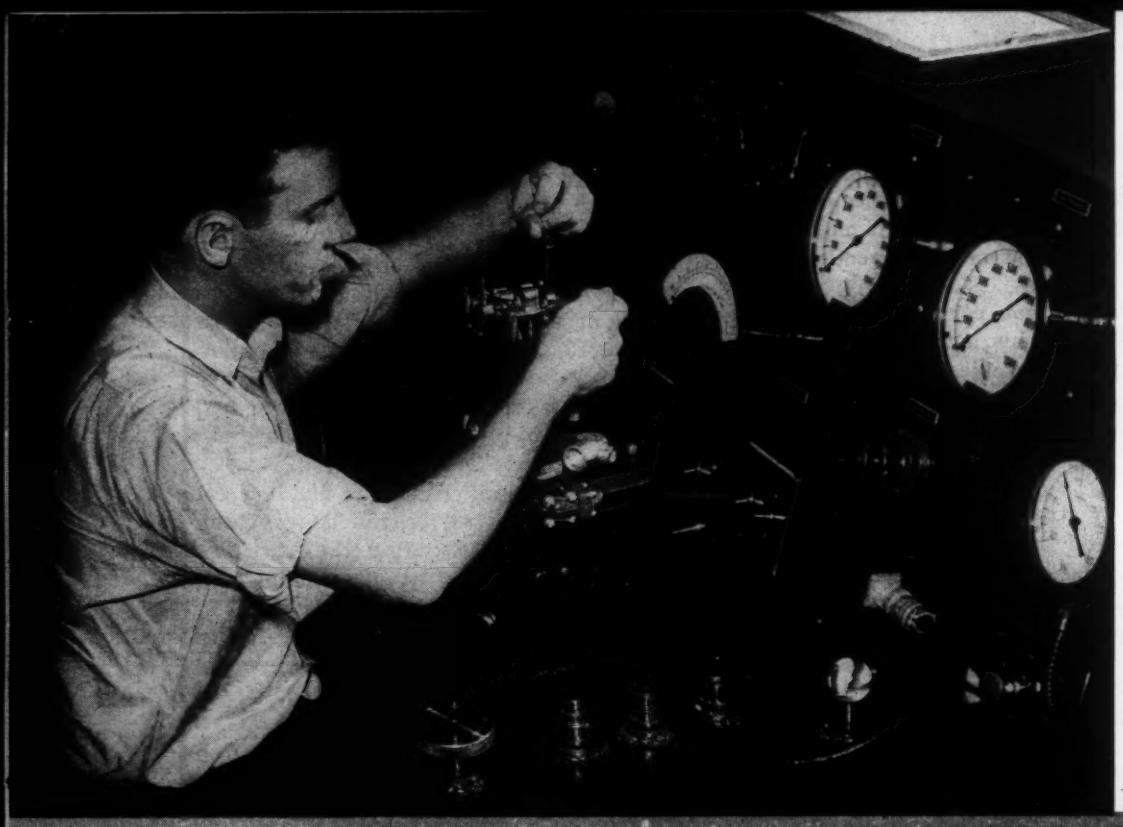


Fig. 45—Test setup for measuring the performance of an aircraft component. Performance ability can thus be determined with statistical principles

By Dorian Shainin
Chief Engineer
Rath & Strong Inc.
Boston, Mass.

QUALITY CONTROL METHODS Their Use

Part 8–Ascertaining Machine Capability

EXTREMELY broad in aspect, the principles outlined in this part of the series can be used in determining the performance ability of any functioning product, *Fig.* 45. In time these techniques perhaps will be recognized as important tools. Machines or mechanisms are generally designed to do something: develop linear or rotary force, cut metal, provide thrust, sustain wear, govern speed, etc. But repeated runs do not always give exactly the same results. The width of the band of such inherent variation is the important factor that determines the success of the working product. In some cases interest primarily lies with only the total "output" variation for a single item—a machine tool, a pressure gage, a refrigerator. In other instances, however, it is desired to know the characteristic variation that extends among different items of supposedly similar product.

In the realm of machine designs, engineers are naturally interested in the capability of a particular design. On production machines, for instance, they want to know the effect on performance obtained by using different tooling, other feeds or speeds. Even the heat-treated condition of the stock will affect results. As these are altered, they want to know how much narrower or wider the natural tolerance will be.

An important sales feature for enterprising machine builders would be to provide capability charts with the machines, *Fig.* 46. After all the customer is buying performance when he purchases a machine. Instead of making general claims about performance, sell specific, practical results; show control charts of performance under actual operating conditions to be expected.

Control Chart Shows Capability: A control chart shows the variation among averages of samples. This is not the measure of capability desired. The question is, how far will individual pieces depart from a given setting or average? This is a matter of converting the distance between average limits to that greater distance expected, made up of individual values. This information most simply comes from multiplying the distance between the control limits for averages by the square root of the sample size.

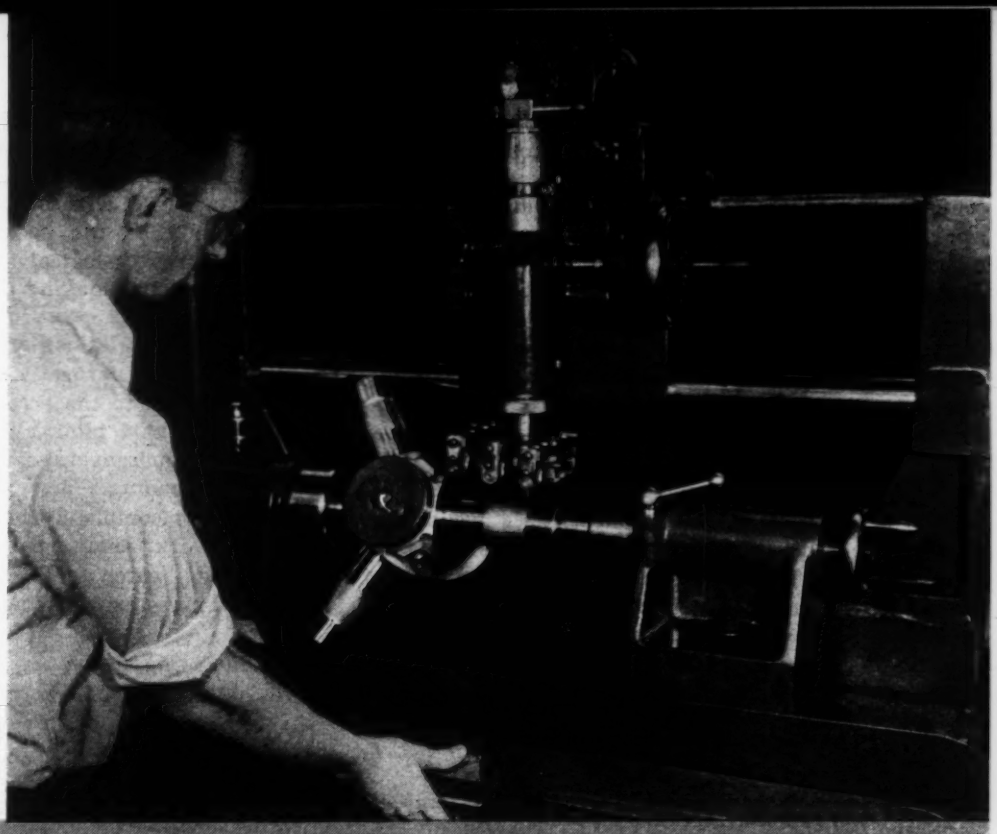


Fig. 46—For production machines, a run of at least 30 parts provides the basis for a capability chart

n Design

Regardless of the machine, mechanism or process involved, capability or performance characteristics can be readily determined and predicted with assurance by SQC methods

The conversion points up once again the importance of proper or rational subgrouping in selecting samples. The measure of range the process gives is related to its capability. The average range of ten or more samples, as noted in Part 3, becomes half the distance between control limits for averages by multiplying with a constant factor A_2, listed in TABLE 7 for commonly used sample sizes.

The spread of points found in the range section of the chart must be comparable with that in the average section. Each should fill out about the same way. Approximately two-thirds of the points should lie within the middle one-third region of the total allowable average and range bands.

Average range, of course, can be converted directly nto process capability, without using the distance between control limits for averages, by dividing the average range by the factor d_2, which gives one standard deviation. Multiplying by six then gives the natural tolerance. TABLE 7 shows the factors "six divided by d_2" for the popular sample sizes which can be used as multipliers with the average range to get the natural tolerance or process capability direct.

The basic procedure, then, is to take any product, machine, or what have you and operate it for a minimum of 30 times, measuring the results each time. With these results an average and range chart is plotted using a subgroup size of three. Each of the ten plotted range points should fall beneath their control limit which comes from the average of the ten ranges multiplied by the factor D_4, TABLE 7. Next, the average range is multiplied by A_2. If each average point

Table 7—Factors for Determining Capability

Sample size, n	A_2	$6/d_2$	D_4
2	1.88	5.30	3.27
3	1.02	3.54	2.57
4	0.73	2.92	2.28
5	0.58	2.58	2.11
6	0.48	2.37	2.00

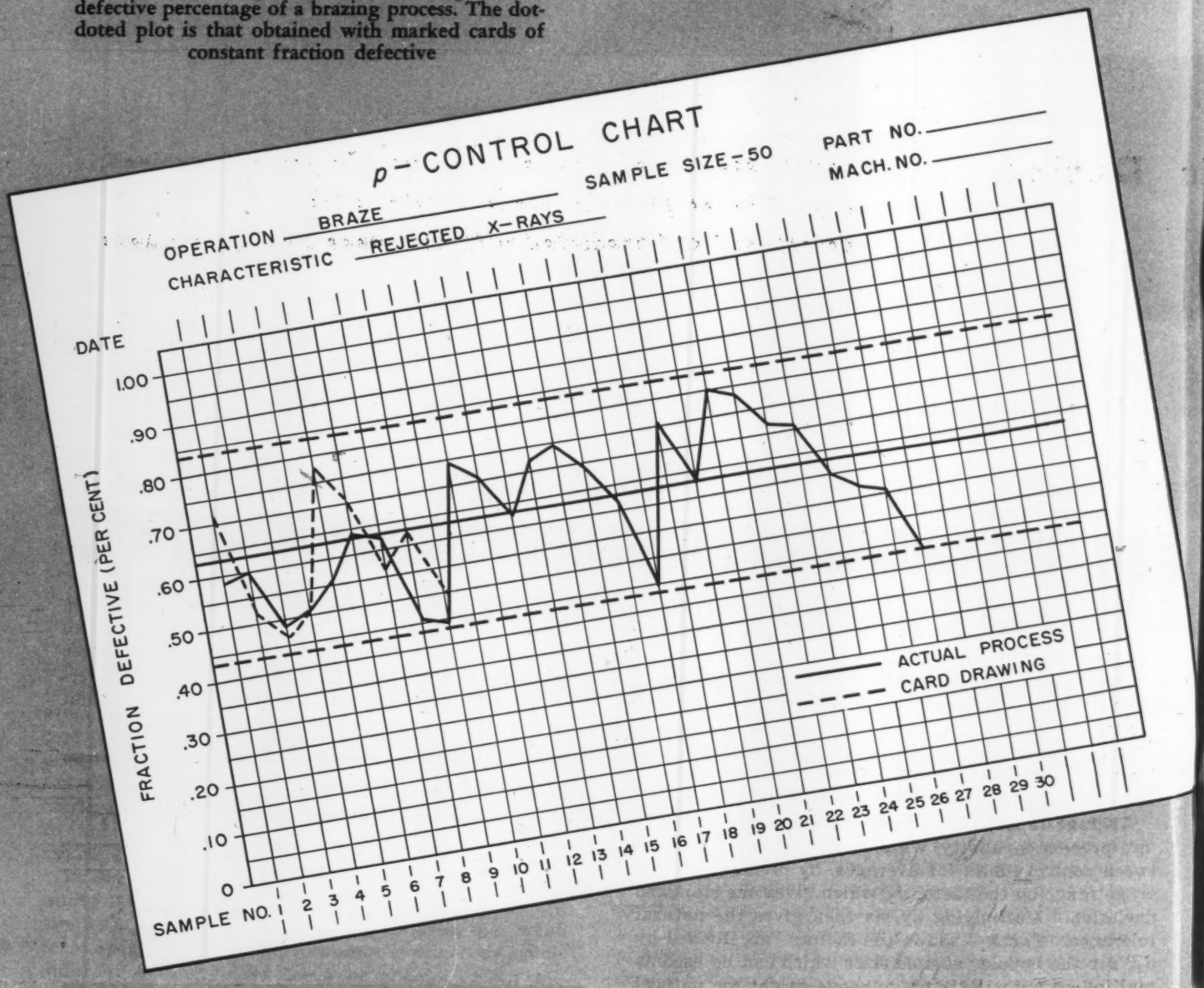
also falls within plus and minus this band about the grand average of the ten sample averages, the process or function is in control. However, it should also be confirmed that the points are distributed about as would be expected from pure chance, with most of them coming within the middle third of the average and range bands.

As a final step, the average range multiplied by the factor $6/d_2$ will provide an estimate of the spread within which all but three pieces or results per thousand can be expected to fall. This is the practical, maximum range of performance of the product or equipment that can be expected in the future if no new disturbing influences occur.

Such a test tells just what experiences a customer might encounter. Too many manufacturers are instead still blithely selling their product on the basis of one or two runs or sometimes on the basis of the best performance they ever got from an exceptional run that is fondly remembered.

Measurement Errors: Control chart readings can be no better than the accuracy of the gaging device. This apparently logical statement belies a statistical truth. A little thinking along the statistical lines emphasized by this series of articles points up the fact that chance variations are not strictly additive. Any single reading naturally falls from its true value an amount equal to the error the gage contributes. But a control chart plots averages of samples and their ranges. Each average and range consists of more than one reading. Now, if the variations in gage reading remain completely independent of the actual size of the work being measured, the error seems to be somewhat "eaten up" or averaged out over the readings. This is exactly the effect obtained from the sta-

Fig. 47—Process capability study showing fraction defective percentage of a brazing process. The dot-doted plot is that obtained with marked cards of constant fraction defective



tistical addition of tolerances discussed in Part 7.

The variation in gage reading (error of the gage) can be found simply by taking repeat readings on the same spot of a single part and running a control chart of the nonrepeatability of results. This procedure should be done again on a part of somewhat different size, perhaps at another point within the tolerance of the dimension in question. If substantially the same variation is experienced regardless of the basic size being measured, a necessary requirement to permit statistical additions will have been established.

The nomogram, *Fig.* 43, shown in Part 7 can apply. The "center" or "assembly" scale represents the tolerance of actual readings, the result of the true variation and error variation combined. The error variation can be found by repeat readings on the same piece. Place this variation on a side scale and that of the apparent process capability on the center scale. On the other side scale can be read the true natural tolerance of the work. The error factor will have been taken out.

The error in gage repeatability is usually only a fraction of the product variation. Some trial nomogram entries will show the error in such cases can be disregarded. It is nice to know that its contribution, however, can be measured and found through the aid of this method of statistical combination.

Capability determinations cannot use an infinite amount of data, so the results are subject to a sampling error. It is kept small by taking at least 10 to 25 subgroups before making an estimate. But measurement errors also "add" to the sampling error. A control chart deals with an average of averages, and with an average of ranges, so the term that could be *statistically* subtracted from the actual control chart averages will be the average of the errors. That average error can be expected to be still smaller; it can be safely neglected in considering the accuracy of a control chart as a measure of the capability of any process or product.

Assignable Causes of Extra Variation: In filling out a chart for a process capability study, all the points should fall within the control limits to denote a steady operation of the characteristics of the process that cause variations in results. A stable variation pattern as contrasted to an erratic one means no assignable causes of variation exist or can be readily found. The variation is just chance.

When this situation exists the natural tolerance or capability of a process can be readily computed. But, if some of the points fall beyond a control limit, then an assignable cause of more than chance variation can usually be found. It would not be sound to estimate capability from such data. Often the causes are simply and almost immediately found by the one making the capability study. The difficulty may lie either with the operator, the material, or the machine (which can include the gaging device). An early guess may be statistically checked to see if it is the right one. Another ten subgroups, run after the change, will show whether the effect of the assignable cause has disappeared. The next part of this series will take up ways and means of locating such assignable causes when they instead prove to be elusive.

Another feature of process troubleshooting will show how to reduce natural tolerances, those found to be running within statistical control. Sometimes such a tolerance, although readily and accurately determined, has a spread too great to meet specification requirements. An inherent variable needs to be reduced or eliminated to cut down this natural tolerance. Some feature of the basic process needs to be altered. Troubleshooting techniques will lead to that feature.

Process Capability by Attributes: The yield of a certain brazing operation was 37 per cent for a two-year period directly following the design of the part. The structural integrity of the brazed joints happened to be one of the most critical requirements for the satisfactory performance of the product. X-rays taken of each of the important joints often showed voids or other discontinuities of such an extent that they were unacceptable and more than half of the output had to be scrapped. The selling price of the brazed assembly naturally reflected this low-yield condition.

Experts had been working on the problem for some time, but these consultants along with the company's engineers were having only sporadic success. Now and then a change they made seemed to bring down the fraction defective of the output for a short period. But then for some unknown reason up went the scrap rate again. The introduction of unknown, new changes were always blamed. Looking back on that rather serious situation one cannot help think, "how confused can a technically competent group get about such a puzzling problem?" No one was armed with these statistical tools. An attempt could not be made to determine the inherent ability of the process.

In *Fig.* 47 is shown the first step taken in trying to solve this scramble. A p or fraction defective chart was plotted from the results tabulated in a book kept by the brazing operator. The serial number of each brazed unit had been listed for two years along with the disposition of the X-ray inspection, scrap or accept. Only the last year's data were plotted. The engineer chose 50 consecutive items for each sample or subgroup.

First, all the scrapped assemblies were added and the total divided by the total assemblies processed. This gave an average p value of 0.63. Next, the chart of *Fig.* 18 of Part 3 of this series showed upper and lower control limits as 0.83 and 0.43. Immediately an important thing was revealed. All the points fell within the control limits. That meant there was no statistical evidence that anything significant had been done during the year to change the level of the capability of this process. In other words it acted for the entire year just as a process would, which was producing random samples from a *constant* per cent defective of 0.63. A quick check of the previous year's entries showed that it, too, had an average p of 0.63.

Management was not convinced about this conclusion when first confronted with the statistical analysis. After all, reasoned the executive engineers, cer-

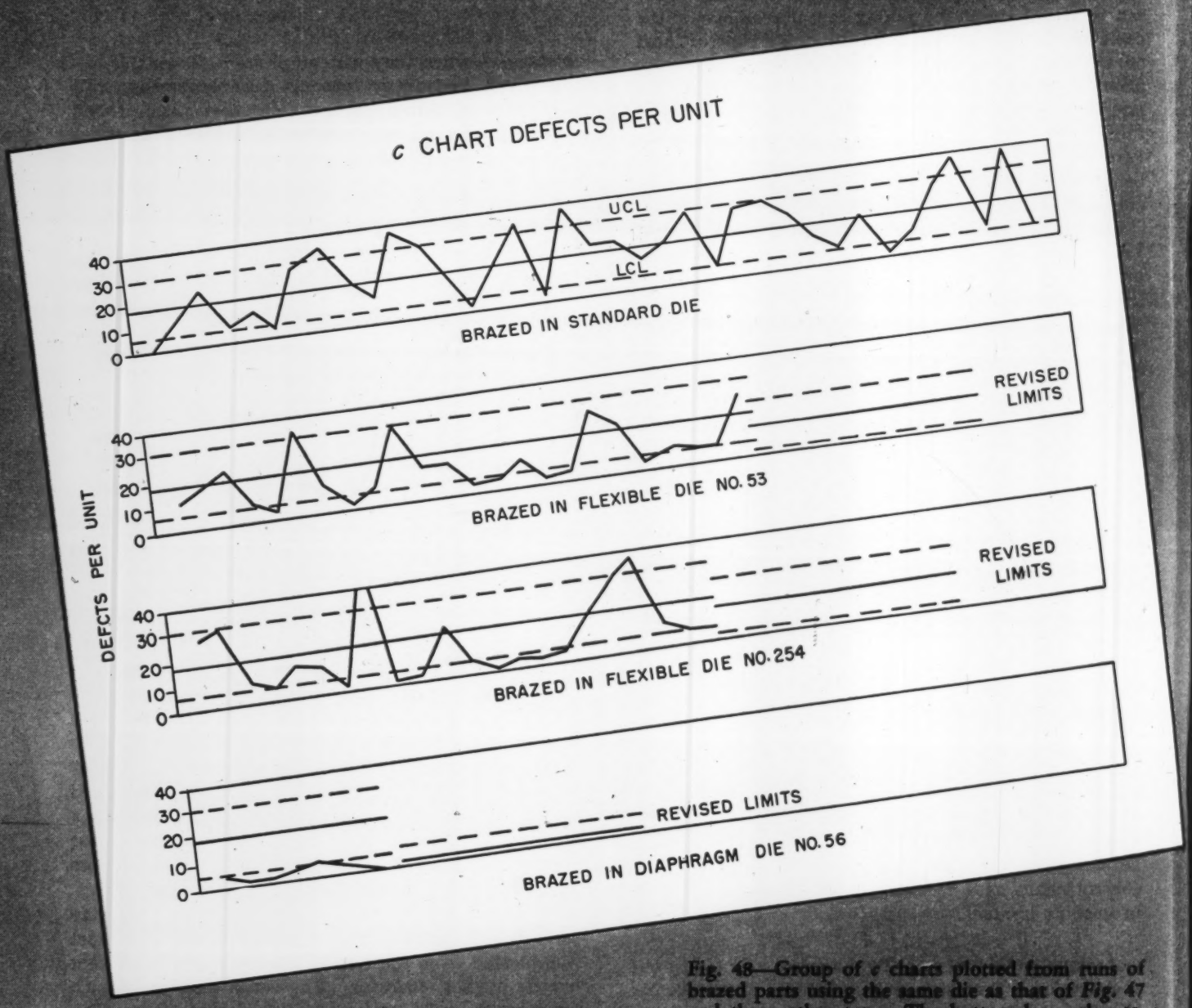


Fig. 48—Group of *c* charts plotted from runs of brazed parts using the same die as that of *Fig.* 47 and three other types. The bottom low value resulted with a pressurized die fixture

tain changes had been experimentally shown to have real effects: the cleanliness of the mating surfaces, the purity of the brazing flux, the dimensions of the parts before they were inserted in the brazing dies, etc. From test specimens definite correlation seemed to exist between some of these changes and the successive poor results. How then could one conclude that all the previous attempts to improve these characteristics in the production process were to no avail?

The quality control engineer had to take an enterprising step; he got two decks of cards, discarding four of them. The remaining 100 cards were marked; 63 as defective and 37 as acceptable. The broken line graph on the *p* chart represented random dealings of 50 cards to a hand. From each hand dealt, the number of defective cards—doubled—gave the fraction defective. The cards were then all reshuffled for the next draw. The fact that the card drawings, from a deck of constant fraction defective, acted virtually the same as did the brazing process put the point across.

Another Capability Check Solves the Problem: What could quality control do to answer the next, now logical, question, "How can this 'constant' process be corrected?" Admittedly, a shot in the dark had to be taken. The analysis seemed to be beyond the point where a brazing expert could take over. Now that the statistician had established his point, he was looked to for a way to bring down the per cent defective of the process.

QUALITY CONTROL METHODS

The quality control engineer was no more of an authority on brazing than he was on many other processes upon which he was able to shed some analysis light, but he could follow an underlying principle. The rule—a constant fraction defective will prevail until a basic change is made in the process. This directive is in contrast to the previous attempts by the experts. To a statistician, they were looking for assignable causes of extra or erratic variation. The *p* chart clearly shows they did not exist.

As a first guess for a good basic change to the process, one could try to change the most evident thing he saw. In this case it appeared to be the brazing dies. A little questioning on this point revealed that there were in fact a few other dies of different designs over in a corner of the shop, gathering dust. Each had been tried and then discarded because of poor results of one sort or another. A request that these dies be cleaned off and tried again was granted. Figures for statistical analyses would be obtained.

As a control, the engineer first obtained data on the dies used in production. Here each X-ray picture was considered as a subgroup of one. The number of voids counted per picture became the number of defects per sample. A *c* chart was plotted. The top chart, *Fig.* 48 shows these results from the standard die. The average number of defects per X-ray picture and the control limits were drawn as described in Part 6.

Although the standard process ran out of control, because of the strict mathematical conditions behind the theory of a *c* chart, it was known that only an approximation to them was being obtained in this example of practice. And it could be a useful estimation. With great room for defects, rather few were occurring but the chance of that average number happening was apparently not close enough to being constant to fit the strict model. Perhaps the biggest contributor to this trouble was the need for defining a minimum void area that would be counted. The X-ray films showed many spots running from pin-point size on up. So it was arbitrarily decided that only those having an area greater than ⅛ by ⅛-inch would be counted.

Now that the control could serve as a basis for comparison, the chart was ready for test results from another die, called the flexible die. Actually, this was a standard production die that had been accidently cracked. Because of the special shape of the assembly being brazed, the die was dubbed "flexible." It might in the cracked condition lend itself more readily to accommodating the contour of the assembly. Results did show a noticeable improvement. More of the X-ray void counts fell in the lower region of the chart. The average *c* value came out definitely lower as shown in the right-hand side of the second chart along with the new control limits for the flexible die.

This interesting result encouraged the order that another standard die be made flexible. It was purposely cracked. The third chart shows virtually the same improvement again as compared to the original control limits. Certainly here was one way to reduce the inherent defectiveness of the basic process.

Another die was tried, one that had been given up some time ago as just a "Rube Goldberg" idea. A portion of the die had been cut away and a metal diaphragm inserted. At the proper portion of the brazing cycle gaseous pressure could be brought in behind the diaphragm to force together the components in a certain critical area. This diaphragm had left a very undesirable looking outline on the surface of the product. But the bottom *c* chart shows that only eight units had to be brazed in this die before it became evident that the improvement shown was no chance difference. It was the real thing. All eight results came below the lower control limit of the standard dies.

Work started immediately on improving the workmanship of the edges of the diaphragm so that the undesirable residual impressions could be eliminated. A little less than a week's work eliminated that difficulty. Orders were given to change all the dies on the production line over to this bladder type die. The previous constant fraction defective of 0.63 dropped immediately to a level of 0.02 where it still is many years later.

Sound Chamber Uses Glass Wool

WEDGES of glass wool encased in wire mesh provide sound deadening in an anechoic chamber built into a new sound laboratory at Westinghouse. Helping to provide an ambient sound level of 10 to 15 decibels, about half that of a residential neighborhood at night, the wedges completely cover the walls, roof and floor of the soundproof room. Each wedge is 8 by 24 inches at its base and 34 inches long. A spring-supported wire net is stretched from all four side walls several feet above the wedges on the floor to provide a working platform. Necessary service lines to operate the various pieces of test equipment drop from the ceiling, and all gages and recording devices are located on control panels in an adjacent room.

A Designer's Guide to Vitreous Coatings

Metal Selection, Processing and Design

By Robert L. Stedfeld
Associate Editor, Machine Design

KEY FACTORS in the design of porcelain-enameled or vitreous-coated components are two—selection of the metal and the specialized processing involved. Although service conditions dictate the type of porcelain enamel to be used, and ultimately determine the metal selection, any design must take into account not only the physical properties of the metal, but also processing restrictions. Special consideration must be given in design to the high temperatures encountered in enameling, the effect of metal fabrication on processing, and other process variables. In addition, the part must be designed to get the most protection from the coating.

This final article will review three basic factors—selection of a metal, processing considerations, and design for enameling—supplementing the two previous articles (December, Page 165 and January, Page 141) in which types, uses and properties of vitreous coatings were outlined.

Metal Selection

Each of the main families of vitreous coatings is formulated to be applied to a specific group of metals. Thus, ceramic coatings are usually formulated for the alloy steels, while a particular group of very low-carbon irons or steels are used for standard porcelain enamels.

The determining factor in using a ferrous metal as a base for standard enamels is the high temperature encountered in firing the enamel. Two effects are evident: (1) a tendency in ferrous sheet to sag, warp or deform and, (2) a tendency towards gas evolution from the surface of the metal, producing blisters and fishscaling. Since these two factors are especially troublesome in sheet metal, special ferrous sheets for porcelain enameling have been used for some time.

Ferrous Sheet Metals: Low metalloid content (carbon, manganese, phosphorus, silicon and sulphur) seems to be the answer to both of the problems. Thus, amount of sag and distortion is decreased with reduction in metalloid content. Gas evolution seems to be caused by reaction of compounds of carbon and iron (carbides) with water vapor or oxides from the enamel or atmosphere—promoting "boiling" or "reboiling." The common answer is, again, reduction in carbon content of the steel.

The basic requirements, therefore, for a ferrous sheet with good enameling properties are very low metalloid content—particularly carbon which must not be over 0.10 per cent. The metal should be free from laminations, slag enclosures, gas pockets, and

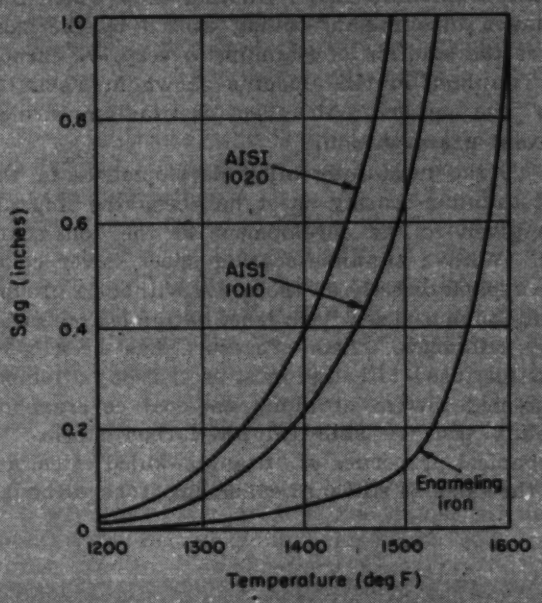
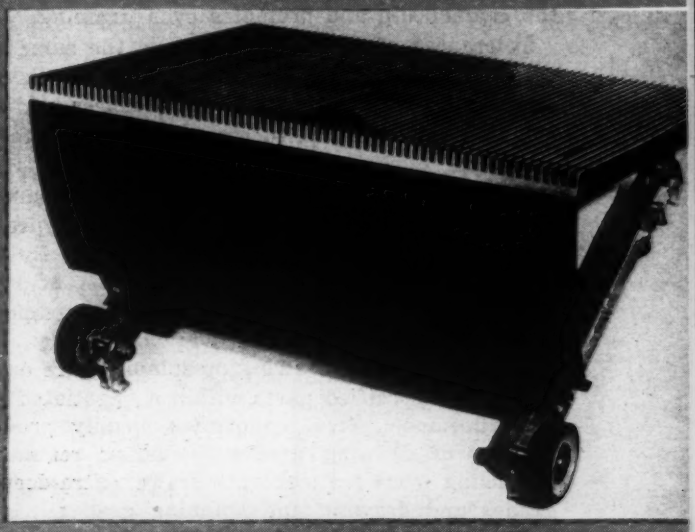


Fig. 1 — Sag of enameling iron compared to low-carbon steel at porcelain-enamel firing temperatures



Photo, courtesy Porcelain Enamel Institute

Porcelain-enameled escalator risers must be able to withstand impact and abrasion. Fabricated from enameling stock, these risers conform to close tolerances for efficient operation

High temperature and corrosion are successfully combatted by ceramic coating this jet-engine liner. The sheet-metal liner is fabricated in two pieces, joined at the seam indicated. A thin ceramic coating is then applied to the whole liner.

Photo, courtesy Borreure Porcelain Enamel Co.

solid or gaseous impurities which might cause surface defects. It should have minimum warpage, sagging or deformation at enameling temperatures or when evaluated in accordance with tests outlined in TABLE 1. In addition, it should have good gas and electric-welding properties, be adaptable to forming or drawing, and have a surface suitable for enameling.

Regular AISI and SAE-composition steels are not usually considered satisfactory for standard porcelain-enamel coatings, although some low-carbon cold-rolled steels with up to 0.50 per cent carbon can be enameled. Hot-rolled steel is unsatisfactory. Special handling is usually necessary to support cold-rolled steel parts while firing, and often low-temperature firing frits must be used. The accepted and preferred practice is to use a sheet-iron or steel developed particularly for porcelain enameling except where the higher strength of standard cold-rolled steel is necessary and a tendency toward warping in the finished part is permissible.

ENAMELING IRON: These special sheets, known as "enameling sheets," are fundamentally very low-carbon basic open-hearth rimmed iron or steel. Typical compositions are shown in TABLE 2. Carbon content of all of these metals is below 0.10 per cent, but in the upper range of carbon content special handling or processing may be necessary.

Standard enameling irons have much higher resistance to sagging at temperatures encountered in en-

ameling, *Fig.* 1, than conventional low-carbon steels. In addition these sheets are furnished cold rolled with a uniform, slightly roughened surface which retains the enamel slip and promotes even draining.

Tolerances of the basic sheet are the same as for cold-rolled sheets,[1] although enameling stock can be produced to restricted thickness tolerances, and can be supplied stretcher-leveled, resquared and sheared to sketches.

Two grades are commonly produced—commercial quality and drawing quality. The first is processed to minimize surface disturbances such as fluting or stretcher strains, and must be capable of bending 180 degrees in any direction at room temperature without visible cracking. Drawing-quality sheets, suitable for severe drawing or spinning, are expected to produce specified parts within a negotiated breakage allowance. Steel companies usually produce a number of drawing grades, including regular-draw enameling irons for moderate draws, extra-deep-draw grades and drawing and spinning grades.

Physical properties of enameling sheets are similar to ingot irons and are in these ranges:

Tensile strength (thousand psi)	38 to 48
Yield point (thousand psi)	18 to 32
Elongation (% in 2 inches)	up to 48
Hardness (Rockwell B)	33 to 52

Thus, one typical enameling iron has the following minimum properties:

Tensile strength (thousand psi)	44
Yield point (thousand psi)	27.5
Elongation (% in 8 inches)	25
Hardness (Rockwell B)	50

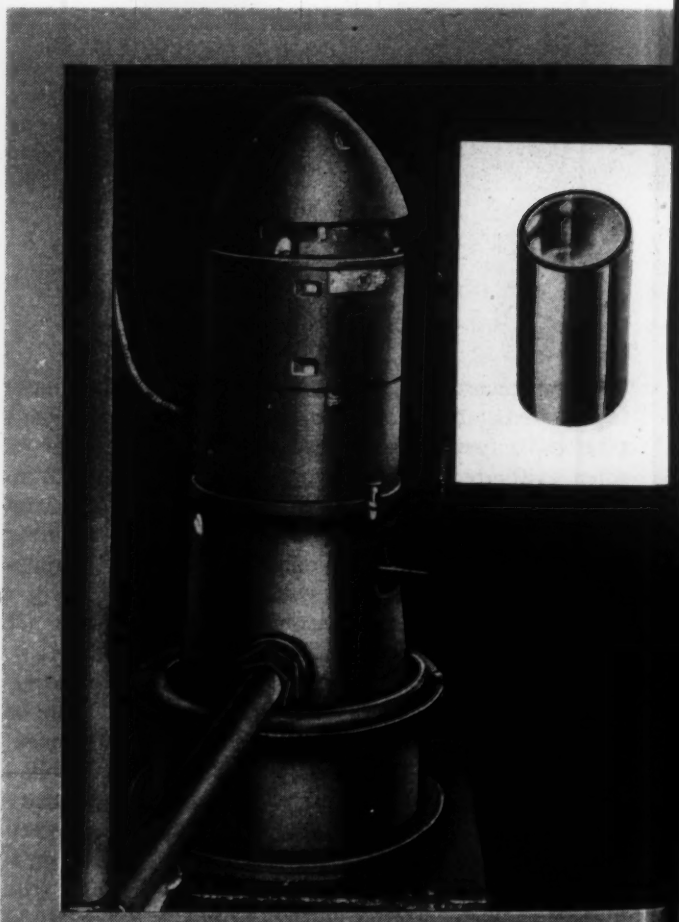
For deep-drawing sheets the yield point drops to 22,000 to 27,000 psi; elongation is about 38 per cent in 2 inches; and Rockwell B hardness is about 37. Olsen test readings show a corresponding increase, being about 0.35-inch for regular 20-gage (0.0375-inch) stock and 0.4-inch for the deep-drawing sheets.

[1] References are tabulated at end of article.

TITANIUM-BEARING IRON: Another step which has been taken to eliminate boiling caused by the base metal is the addition of titanium to very low-carbon iron. Titanium, in the amounts shown in TABLE 2, "binds" the carbon in the form of titanium carbide to prevent gas evolution.

One of the most interesting developments in the use of titanium-bearing sheet has been the impetus it has given to the development of the "one-coat" enamel. With a titanium-bearing sheet, cover coats can be applied directly on the metal without a ground coat, although a nickel flash must be applied for satisfactory adherence. This procedure has been very successfully used, although most present-day attempts are directed toward attaining one-coat coverage on enameling iron or standard low-carbon steels.

Mechanical properties of "titanium-killed" steel are about the same as standard enameling irons, although



Photo, courtesy Porcelain Enamel Institute

Porcelain-enameled bearings enable this deep-well pump to run 24 hours a day at 1800 rpm, carrying fuel oil with a high sulphur content. Designed for use in corrosive fluids, the bearings consist of a porcelain-enameled sleeve and synthetic-rubber journal. They are self-lubricating in practically any liquid.

Table 1—Tests for Firing Characteristics of Sheet Metals

Warpage

Purpose: To determine the amount of warpage of rectangular porcelain-enameled flatware.

Results: *Twist,* or deviation of the specimen edges from a reference plane, is expressed as a percentage per foot of length. The *waviness index,* an integer, is an expression of the deviation from the theoretical plane of the surface when corners of the specimen are forced into a horizontal plane.

Method: Twist is computed from measurements of the deviation of the test piece when placed in a free position against a vertical plane surface. The waviness index is computed by clamping the test piece on a horizontal plane surface and measuring deviations on the longitudinal and lateral centerlines, and on both diagonals.

Test: T-3.*

Sagging

Purpose: To determine the ability of a metal to support its own weight at temperatures used in firing porcelain enamels.

Results: Deflection in the test specimen represents the amount of *sag,* inches.

Method: Three 2 by 12 inch test specimens, coated with ground-coat enamel, are supported on parallel horizontal rods 10 inches apart and fired at 1600 F for 10 minutes. The difference between the amount of deflection at the midpoint of the specimen before and after firing, as measured by a specially mounted depth micrometer, is taken as the sag.

Test: T-4.*

* Porcelain Enamel Institute.

resistance to sagging is higher. Titanium-bearing 18-gage (0.050-inch) sheet has practically no sag when tested in accordance with the PEI test for sagging (Table 1), whereas standard enameling iron sags approximately 0.25-inch. Sag of 0.30-inch is reported for 24-gage (0.025-inch) titanium-bearing sheet, against 0.80-inch for enameling iron.

Titanium-bearing sheets are produced in both commercial and drawing qualities, to the same standards as enameling stock.

STEELS FOR GLASS-LININGS: Enameling irons are also used for glass-lining enamel applications. "Glass-lining steel A" in TABLE 2 is a typical example, being used for hot-water tanks in which temperatures and pressures require a reasonably high mechanical strength. "Glass-lining steel B" is a type used for large tanks. Metalloid content is fairly low and this steel can be enameled by normal methods without excessive difficulty.

Standard enameling irons, however, must give way to heavy iron plate or steel for higher strength in applications involving high pressures and temperatures. For these applications, two types of ferrous metal are used.

The first is low-carbon basic open-hearth plate, generally of flange quality. Thickness may range up to 1 inch, and wet or dry-process enameling is used. Fundamentally an ingot iron, this type of plate is covered in ASTM specification A 129-47, Type A,[2] which gives a tensile strength of 44,000 psi, yield strength of 27,500 psi, and elongation of 25 per cent in 8 inches. Comparable compositions are covered in ASTM specifications A 178-47, Type B,[3] and A 83-46, Type B.[4]

A second base metal—regular carbon steel—may be required. Since metalloid content usually runs fairly high, special enameling procedures, mostly restricted to the manufacture of large chemical-processing equipment, must be used. Enamel is sprayed by the wet process, and is fired in an inert atmosphere. Thus oxygen and water vapors which cause boiling are excluded.

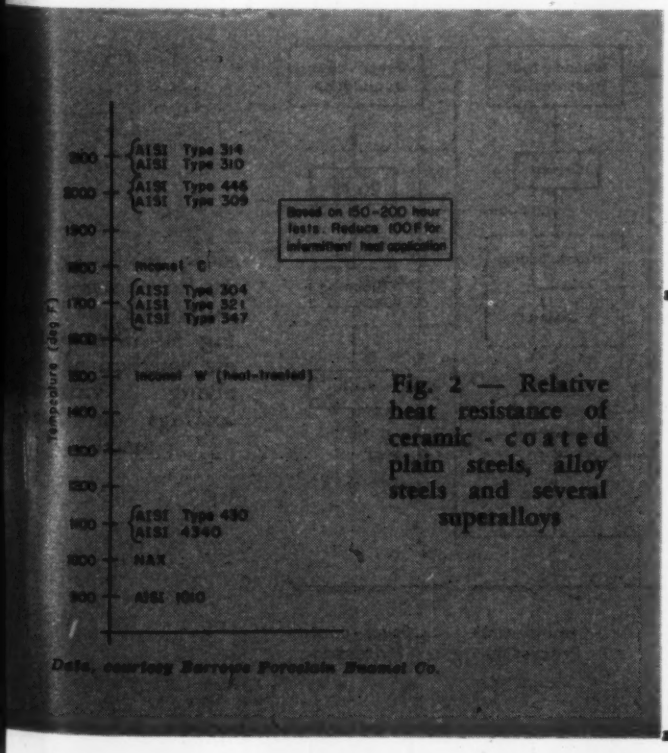


Fig. 2 — Relative heat resistance of ceramic-coated plain steels, alloy steels and several superalloys

Casting Metals: Cast iron, cast steel and malleable iron are all acceptable for porcelain enameling, however cast steel is preferred for parts subject to strong corrosives. Although both white and gray cast irons can be easily enameled, gray irons are now used almost exclusively.

The problem of boiling is handled in a slightly different way in cast irons. Since two or more coats are usually applied, and firing time is long, the ground or "grip" coat is allowed to boil during firing, sometimes quite violently. Toward the end of the process the enamel quiets down and forms a smooth layer. Boiling on the second firing (so-called "ground-coat boiling") sometimes occurs, but can easily be controlled if the casting is correctly designed.

Consequently, carbon and metalloid content in ferrous casting metals is not as critical a factor as in the sheet metals. Although total carbon may be high, combined carbon should be low. Typical cast-iron compositions for enameling are given in TABLE 3.

The use of a "carbon-content equivalent" has been found helpful in determining whether a cast iron has suitable temperature and thermal-shock characteristics for enameling. This carbon-content equivalent $= C + 0.3\ (Si + P)$ where C = carbon content, per cent; Si = silicon content, per cent; and P = phosphorus content, per cent.

A carbon-content equivalent of about 4.3 is considered excellent for enameling. ASTM Specification A 319-48 T[8] outlines typical carbon-content equivalents and other specifications for gray irons very similar to those used for enameled castings.

The casting must be of high quality—reasonably uniform and dense in structure, free from segregation, porosity and slag enclosures. The surface should be such that sand blasting will leave a smooth surface free from appreciable defects.

Metals for Ceramic Coating: Selecting a metal for ceramic coating involves a much more complex set of variables than selection for simple enameling. Design of parts for high temperatures requires a more

Table 2—Typical Compositions of Ferrous Sheet for Enameling

Type of Sheet	Element				
	C (%)	Mn (%)	S (%)	P (%)	Si (%)
Ingot iron	0.015	0.025	0.025	0.005	*
Enameling iron A	0.013	0.023	0.02	0.0075	*
Enameling iron B	0.03	0.05†	0.025	0.01	...
Titanium-bearing iron§	0.05	0.25	0.03	0.01	0.10
Enameling steel A	0.05	0.30	0.035	0.005	*
Enameling steel B‡	0.06	0.32	0.027	0.008	0.003
Glass-lining steel A	0.02	0.04	0.025	0.004	0.007
Glass-lining steel B	0.09	0.48	0.03	0.02	0.01
AISI 1010	0.10	0.45	0.05	0.04	...

* Trace. † Up to 0.15% for improved drawing quality. § Plus 0.25 Ti. ‡ Plus 0.07% Cu.

thorough study of structural properties of the metal, since ceramic coatings only protect against corrosion and intergranular corrosion, and aid in preventing failure due to hot spots and heat flow. Physical properties at high temperatures, such as strength, age hardenability and creep rate, depend only on the steel used, and must be considered in any design.[9]

Any sheet metal component for high-temperature service must usually be subjected to thorough tests under simulated or actual operating conditions before finally being considered acceptable. Many laboratory tests have been made of combinations of metals and ceramic coatings under various temperature and stress conditions. Although these tests can be accepted as an indication of areas for a designer to investigate, they cannot be accepted as final criteria of serviceability. As a matter of actual procedure, enamelers and ceramic-coating manufacturers will finally endorse a coating for specific service only when it has been thoroughly tried out under expected service conditions.

Metals on which most ceramic coatings have been used fall into three classes: (1) the "ordinary" steels such as the AISI 10XX, 41XX and 43XX series, NAX steels, etc. in which the effort has been substitution for alloy steels; (2) the AISI Type 300 and 400 series stainless and heat-resisting steels, 19-9DL, Armco 17-14 CuMo and similar "moderate" alloy steels, which can substitute for unprotected "superalloys" and; (3) the richer alloys and "superalloys," such as the Inconel series, Hastelloy C, Stellite 21, N-155, etc., in which the effort has been to prevent intergranular corrosion and extend service life.

Most recent work has been in the second group, the stainless and heat-resisting alloys. Ceramic-coated metals in this group have in many cases been completely satisfactory for applications in which only the superalloys could previously have been used. Ceramic coatings on metals in the third group, however, have imparted service life well in excess of the life of the unprotected metal in severe applications.

Listed in TABLE 4 are metals for ceramic coating which have been most extensively tested. An indication of the relative heat resistance of some of these metals can be gained from *Fig.* 2, which suggests maximum temperatures based only on heat-resisting properties. Taken principally from tests running from 150 to 200 hours in length, data from *Fig.* 2 cannot be categorically applied to more extended time applications, nor is any attempt made to consider physical properties at high temperatures.

For adequate adherence, metals to be ceramic coated must have the ability to develop a highly adherent oxide upon firing, essentially insoluble in the coating and capable of existing for 15 to 20 minutes at 1600 F or higher. They must have a slightly etched surface, free from rolled-in scale, pits or defects, and must also have a low hydrogen and included gas content.

Aluminum Alloys: Preferable aluminum alloys for

Table 3—Composition of Cast Irons for Enameling

Element	Permissible Range* (%)	Ideal Range* (%)	Typical A† (%)	Typical B§ (%)
Silicon	2.25-3.00	2.50-2.60	2.50	2.50
Phosphorus	0.60-0.95	0.60-0.70	0.70	0.75
Manganese	0.45-0.65	0.45-0.60	0.60	0.70
Sulphur	0.05-0.10	<0.09	0.08	0.075
Total Carbon	3.25-3.60	3.25-3.35	3.40	3.30
Combined	0.22-0.52	...	0.40	0.50
Free	2.80-3.60	...	3.00	2.80

* Reference 5. † Reference 6. § Reference 7.

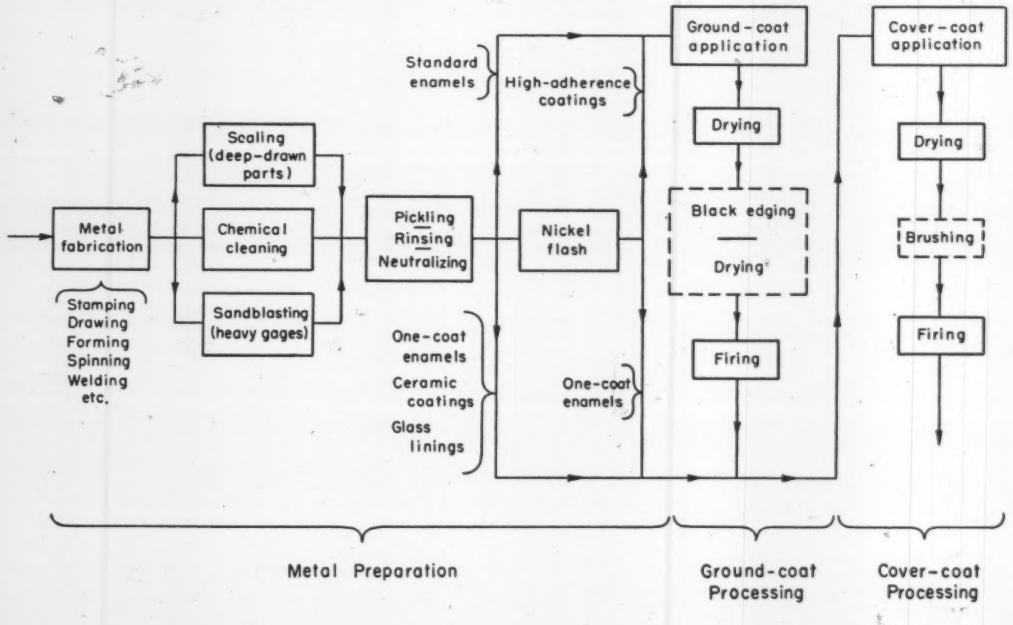


Fig. 3—"Wet process" method of applying vitreous coatings on sheet metal

enameling are wrought alloys Nos. 2S, 3S, 53S and 61S. Casting alloy No. 43 is also very satisfactory.

Enamel Processing

As mentioned in previous articles, two methods are used for processing porcelain enamels and related vitreous coatings—the wet process and the dry process.

Wet-Process Enameling: After fabrication of sheet-metal parts, three methods, as shown in *Fig.* 3, may be used to clean the component. The first, scaling, consists of heating the part at 1200-1300 F until all organic matter (oil, grease, etc.) has been burned off. Highly efficient, but expensive, scaling is now used primarily for deep-drawn parts and parts having rolled edges or flanges, in which case the heating improves enameling qualities by annealing the part.

Chemical cleaning consists of immersing the part in a boiling alkali solution. Sandblasting is used only on heavier sheet-metal parts, since it must generally be accompanied by chemical cleaning or scaling to remove oil and grease.

Removal of oxide is accomplished by pickling, after which the pickling solution is rinsed off and neutralized. In some plants a nickel dip, in which a flash nickel plate is applied, is used to promote adherence and prevent fishscaling.

Application of the ground-coat slip may be by one of several methods. Most common are dipping or slushing; however, if only one side is to be coated or the enamel cannot drain properly, spraying may be used. Automatic and electrostatic spraying have also been utilized successfully on repetitive, large-volume production. After the slip has been dried to a bisque, black-edging or beading enamel may be applied to the edges of the part and dried.

Firing may be in continuous furnaces, in which the piece is hung from an overhead conveyor, or in "box" furnaces, in which the part is supported on "points" or "burning bars." Ground coats are normally fired at 1500 to 1600 F; for cover coats the range is usually 1450 to 1550 F. Common practice, however, is to fire both ground coats and cover coats in the same furnace when continuous furnaces are used, requiring the use of a ground-coat enamel which matures at the same temperature as the cover coat.

Cover coats are processed in much the same way. Spraying is the most common application method; however, dipping, automatic or electrostatic spraying, or flow coating may be used. After drying, the part must be brushed to remove cover-coat bisque from the fired black-edge or beading enamel.

Firing temperatures, although normally 1450 to 1550 F, can run as low as 1350 F for special low-tem-

Table 4—Metals for Ceramic Coating

"Standard" Steels	Alloy Steels		Rich Alloys
AISI 1010	AISI 304	AISI 410	Inconel
AISI 1020	AISI 309	AISI 430	Inconel C
AISI 4130	AISI 310	AISI 446	Inconel X
AISI 4340	AISI 316	17-14 CuMo	Inconel W
NAX steels	AISI 321	17-22A	Hastelloy C
	AISI 347	19-9DL	Stellite 21
	AISI 371		N-155
			S-816

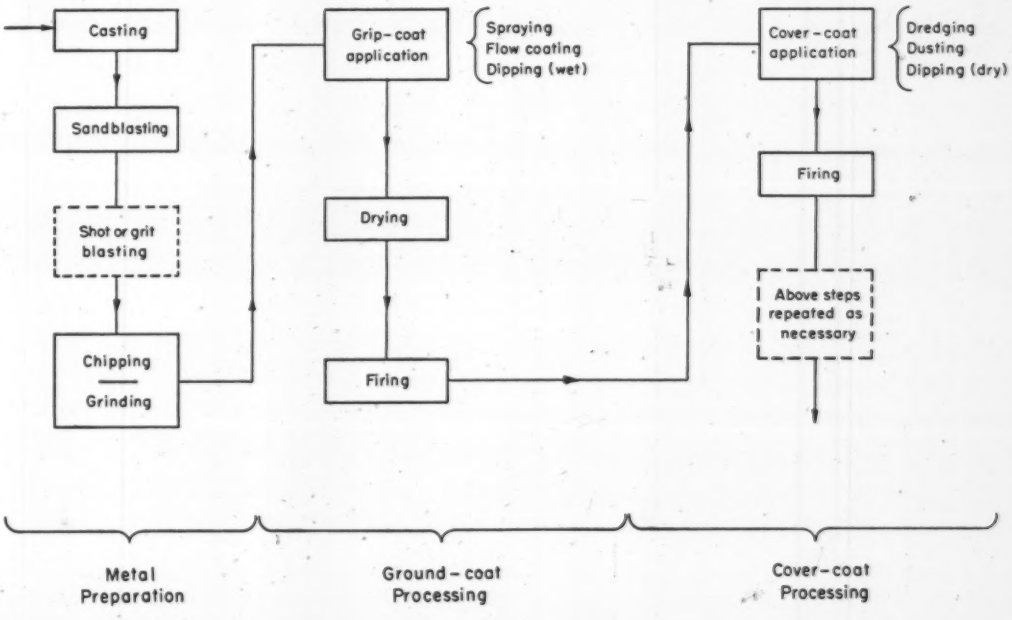
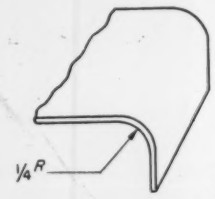


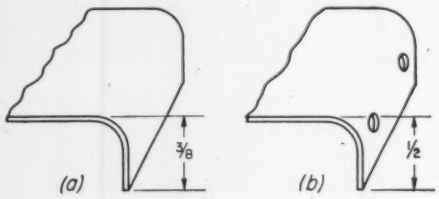
Fig. 4—"Dry process" method of enamel application on castings

Fig. 5—Sheet-Metal Desi



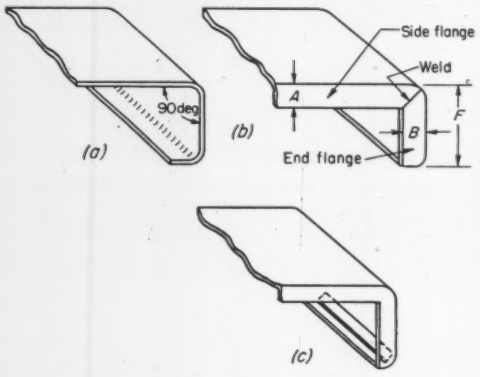
Bend Radius

The single most important step in designing sheet-metal parts for porcelain enameling is to provide a sufficient radius on edges, corners and bends on all formed or drawn parts. A radius of 1/4-inch is desirable, although 3/16-inch is the minimum. When a single dark-colored coat—either dark ground coat or other highly opaque enamel—is used this minimum radius may be reduced somewhat, but in no case should be less than 9/64-inch.



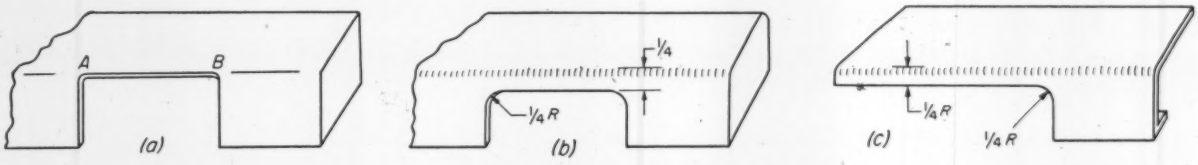
Flanges

Flanges are used for four purposes: to stiffen a piece, thus helping to prevent warping during firing; to provide a rounded edge which helps prevent chipping; for fastening; and as mountings for small assemblies. Flange width, *a*, should be held to a minimum of 3/8-inch. If mounting holes, *b*, are to be punched, a 1/2 or 9/16-inch width is a more desirable minimum.



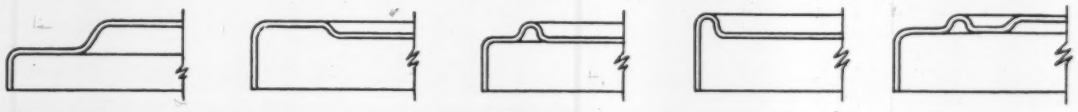
Flange Support

If appearance or design require a large flange on one edge, *a*, it should be adequately supported by end and side flanges, *b*, if it is to be kept straight and at an exact angle during firing. The safest design is to make end flanges equal in depth to the exposed edge flange. Minimum for good design is $A=B=1/3F$, as shown in *b*. If this minimum cannot be maintained because of other design features, a light-gage strip may be welded to both flanges, *c*, although the latter is not desirable. Welding open corners where flanges meet, *b*, is considered a good practice. Welding may be omitted if enamel coatings are thin or dark-colored, but at the risk of decreasing rigidity and increasing the tendency toward warping and chipping. Greater flexibility for mounting can in some cases be provided by welding only the top of the joint. If the piece is unusually long in relation to width of the exposed flange, a bracing strip welded between end flanges, cut off after firing, may be necessary.



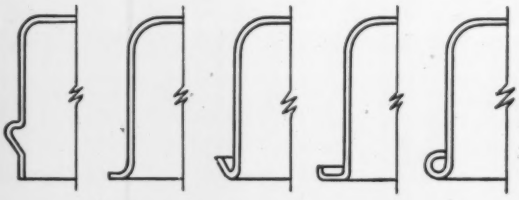
Cutouts in Flanges

Since they tend to weaken the flange, cutouts, notches and large holes should be avoided—especially on narrow flanges. Such cutouts are areas of stress concentration and tend to result in hairlining and chipping on the face of the piece opposite the cutout (*A* and *B* in drawing *a*). If cutouts and notches cannot be avoided, they should have a 1/4-inch or larger radius, *b*, and 1/4-inch of flange should be left between the top of the cutout and the face of the piece. If a variable-depth flange is needed, *c*, the same considerations apply. With this flange, hairlining is apt to occur.



Embossing

Panels and flat areas are frequently embossed to strengthen and stiffen the part. Embossing takes up excess metal in the center of a formed piece which may cause the piece to warp or produce hairlines during firing. All embossing should be symmetrical with the outline of the piece, since unsymmetrical embossing results in uneven stresses which can distort and warp the part. Previously mentioned minimums for bend radii also apply to embossing radii.



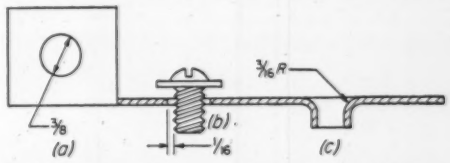
Edge Forming and Beading

Long edges must sometimes be formed instead of flanged when design necessitates the added stiffness but flanging is not possible. Beads or rolled edges are frequently used if parts are symmetrical and a uniformly good edge is needed, but the bead must be large enough so that enamel will not burn off during firing. Beading or edge forming will usually require brushing or black edging for better appearance and to prevent chipping.

Porcelain Enameling

Holes

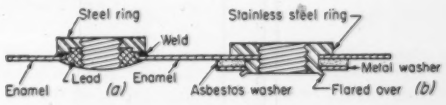
Holes should be large enough to prevent enamel from filling and clogging after firing, unless an extra reaming operation or the use of special reaming screws is permissible. For dipping with automatic equipment, holes should be at least 5/16-inch in diameter, *a*, although ⅜-inch holes are preferable. Bolt holes, *b*, should be punched at least 1/16-inch larger than the nominal bolt diameter to allow for enamel thickness over the edge of the hole. In some cases 1/32-inch is sufficient, but again, the reaming operation may be necessary if the enamel accumulates too heavily. An allowance



of 3/32 or ⅛-inch, where possible, is even better. Where good coverage and appearance are necessary, bolt holes should be extruded, *c*, due to the tendency of enamel to pull away from and burn off sharp edges. Radius of the turned-back edge should be no less than 3/16-inch.

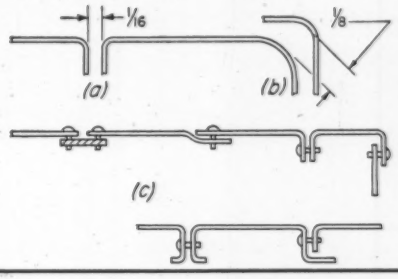
Connections

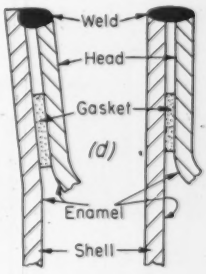
Piping connections which must be corrosion or hot-water resistant (as in hot water tanks) require special handling. Often bare metal is exposed at the edge of the porcelain-enameled part, and mechanical strength must be sufficient to withstand some pressure. The connection at *a* is a good seal and has excellent mechanical strength. The edge of the porcelain-enameled metal is far back under the lead seal, and the ring is welded directly to the porcelain enameled metal. To insure a good bond between the lead and the steel ring, the ring is grooved. The patented connection (A. O. Smith Corp.) at *b* has the additional advantage of covering any crack which might extend back from the hole edge.



Joints and Fitted Parts

Allowance must be made for enamel thickness in designing assemblies involving the fitting together of porcelain enameled parts. Clearance between the mating edges of flat parts, considering the tolerances usually allowed in fabrication plus a possible enamel thickness of as high as 0.05-inch at the edges, is usually recommended as 1/16-inch, *a*. At corners, *b*, this clearance should be increased to ⅛-inch to allow for enamel build-up in inside corners. Several joint designs are shown at *c*. Sealed joints for corrosion-resistant service in tanks, *d*, require protection at the weld. This protection is afforded by an asbestos or glass-tape gasket which, although not necessarily an effective seal in itself, provides a dead-air space which restricts circulation and rapidly fills with corrosion products to cut down rate of corrosion. The joint at left is patented (A. O. Smith Corp.)



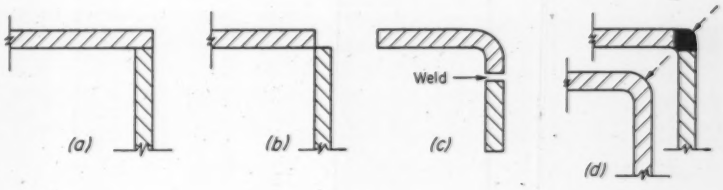


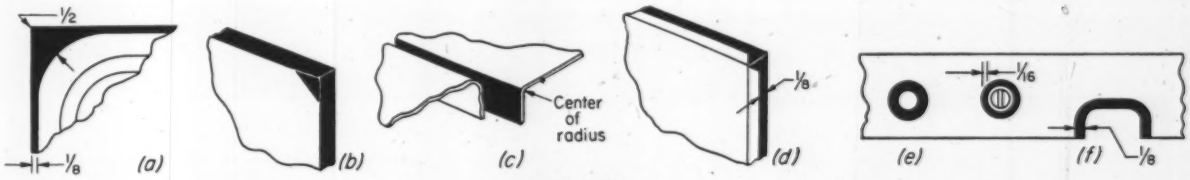
Fasteners

Bolts and self-tapping screws are probably the most widely-used fasteners for porcelain-enameled articles, although a variety of special fasteners have been developed. Spot-welded clips, blind fasteners, self-reaming screws, spring-steel push-on nuts and many fasteners specially designed for porcelain-enameled appliances are widely used. Often washers, grommets or eyelets are utilized to take up the stress imposed by tightening a bolt in order to prevent chipping at the hole, especially if an enameled coating is thick and the cover coat cannot be crushed.

Welding

Corner welds, *a* and *b*, are most frequently employed, although a weld near to but not at the corner, *c*, is less apt to cause chipping and hairlining. An incorrect position for making an edge weld is shown at *a*, since metal can flow from the edge of one blank only. The correct position is at *b*, since metal flows through the joint from both edges. Peening the weld, *d*, provides a rounded inside and outside radius that is desirable. Overlapping unwelded parts, wide spacing of spot welds or double thicknesses of metal should be avoided, since hairlining may occur.





Brushing

Brushing is employed to reduce the thickness of the enamel coating at edges and corners, thus decreasing the possibilities of chipping. Brushing is a hand operation, and consequently should be eliminated where possible. Minimum width of brushing should be ⅛-inch, *a*, with wider brushing in multiples of this width. At corners, width should be increased to ½ or ¾-inch. If a flange is assembled close to or against another part, is invisible, or moves in proximity to another part, it should be brushed over its full width, *b*, and the corner should also be brushed. Brushing should also be carried to the center of radius, *c*. The alternate, less-effective brushing design shown at *d* can be used for exposed parts. Holes and cutouts should be brushed for at least 1/16-inch outside of any mating accessory, *e*, and cutouts should be brushed for a minimum of ⅛-inch around the edge, *f*.

perature firing enamels and as high as 2000 F for ceramic coatings. Enamels for aluminum are normally fired at about 980 F.

Dry-Process Enameling: In many ways dry-process enameling on castings, *Fig.* 4, is much the same as wet-process enameling. After casting, the piece is sandblasted and may also be steel-shot or steel-grit blasted. Any surface imperfections, blemishes and rough spots are chipped or ground off.

The casting then receives an application of thin ground-coat enamel ("bond" or "grip" coat) which may be sprayed, but is more commonly flowed onto the part or applied by dipping or "slushing." The grip coat is then dried and fired. Firing temperatures range between 1150 and 1700 F.

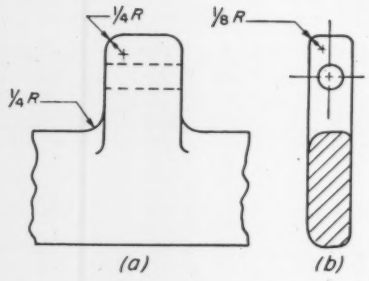
While the casting is red hot, it is removed from the furnace and dry powdered enamel is dusted or dredged on. Occasionally, for small parts, the casting may be dipped into the dry powdered enamel. When the casting has cooled to a point where the enamel no longer adheres, it is returned to the furnace to be refired. This process is repeated until the desired thickness of coating is built up.

Design for Enameling

Importance of good design in obtaining a satisfactory porcelain-enamel coating cannot be overemphasized. Successful use of a porcelain enamel or vitreous coating depends as much on design as on selection of an enamel or on the processing method. A "bad" design, difficult to enamel may necessitate the use of a frit with better enameling properties but less desirable service properties.

Specific design recommendations for sheet-metal and cast parts, outlined in *Figs.* 5 and 6, are based in

Fig. 6—Casting Design for Porcelain Enameling

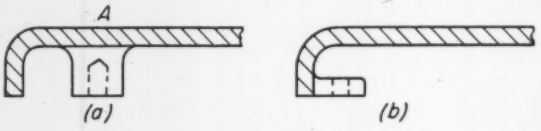


Fillets and Radii

On castings the same general rules regarding radii apply as in sheet-metal design. Fillets and radii of 1/4-inch are desirable, *a*, although radii may, if necessary, be as small as 1/8-inch, *b*. A radius of 1/16-inch is considered satisfactory by some enamelers, but should be increased where possible.

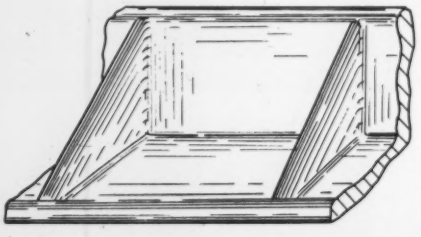
Ribs

Ribs and webs which are too deep and heavy, *a*, will cause hairlining in the enameled surface. An effort should be made to maintain an even section thickness, *b*, and to minimize the difference between alternate light and heavy masses of metal as far as possible.



Lugs

Heavy lugs will cause blistering in the enamel (at *A* in drawing *a*), and should be avoided. Many times a doubled tab, *b*, can be substituted for the lug.



Webs

Uneven strains are sometime impossible to avoid in designing castings. In such cases, thin webs at the proper places may reduce warpage and still permit satisfactory enameling.

part on standard recommendations.[10] To understand reasons behind these recommendations, certain fundamental points should be considered.

Basic Design Factors: Certain factors are basic in any design for enameling. While some may seem obvious, their significance is often overlooked, a common cause of trouble. "Why didn't they show this design to me before they okayed it?" is a frequent question from enamelers, largely caused by violation of one of these fundamental precepts.

ACCESSIBILITY FOR ENAMELING: Method of enamel application must be considered. If the part is to be sprayed, the sprayer must be able to reach all areas to be enameled. If dipped and processed on continuous conveyor lines, the part must have provisions for hanging, and enamel must drain properly when so suspended. Enamel slip often tends to build up on the lower draining edge of the component, leaving a drain mark or heavier coating at this place; thus, if evenness of coatings is important for appearance or fitting together of parts, this draining edge should be hidden. If the piece cannot be so designed, brushing of the cover coat may be necessary.

SHARP EDGES AND RADII: Enamel tends to pull away from sharp edges and small outside radii due to surface tension. Thus the enamel coating may be thin or may "burn off" over these spots. Conversely, enamel will build up to an excessively heavy coating on small inside radii. Thus all radii should be relatively large. Sharp, square metal edges, of course, cannot be avoided on sheet-metal parts, but the part should be designed so that the metal edge is hidden or protected if good appearance or high resistance to acids and corrosion is necessary. Often, where an attractive appearance is required, the cover coat is brushed to expose the dark-colored ground coat or a black-edging enamel is used, since thinness of coating over the edges will not be as apparent.

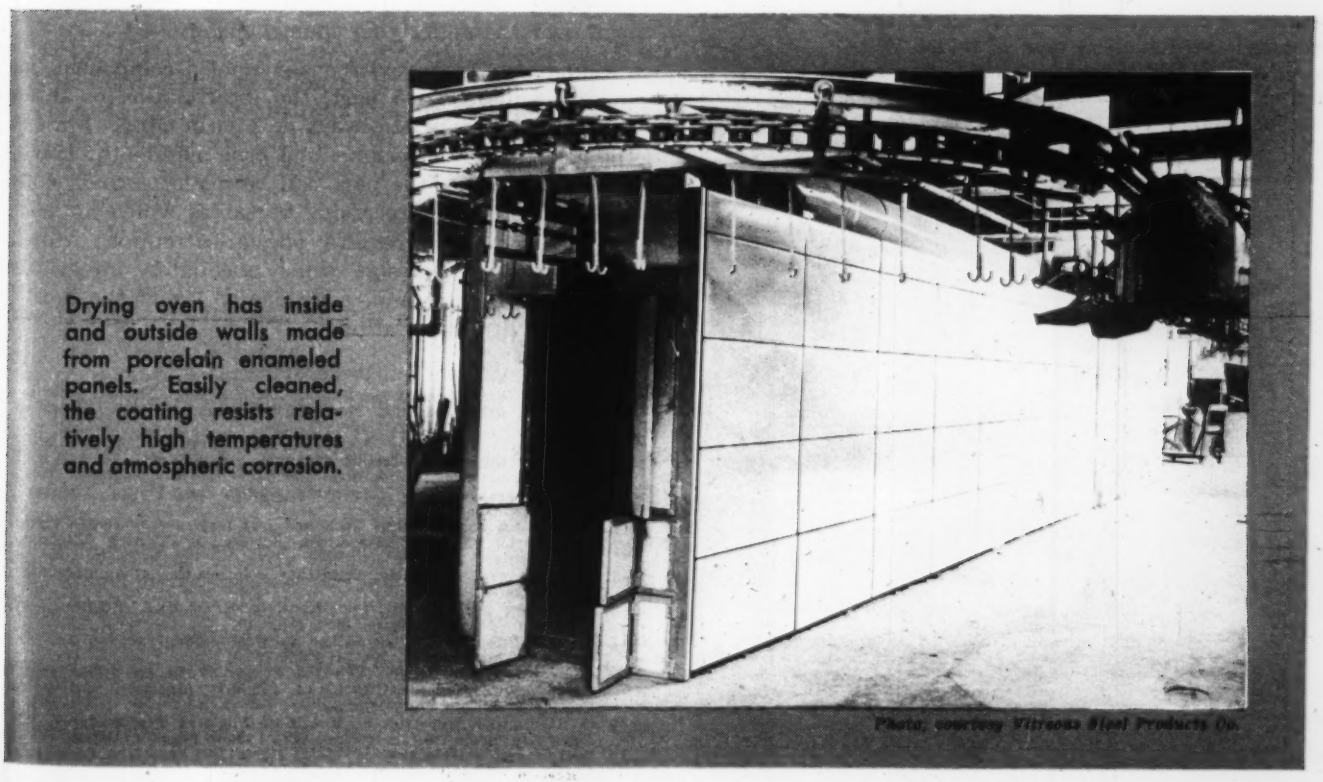
HIGH-TEMPERATURE EFFECTS: In firing, porcelain-enameled parts are subjected to high temperatures which may cause sagging, warping, distortion or defects in the enamel. Sheet-metal parts must be adequately supported and braced, and must be stiff enough to prevent distortion.

Uneven distribution of metal must be avoided in both sheet-metal and cast parts, since the differing thickness and heat capacity will cause the enamel coating to mature at different times in the firing. Thus, one part of the coating may be fired sufficiently while another part may be over or under-fired. Such defects as hairlining, pinholes and fishscaling are often directly traceable to poor design in this respect.

CORRECT METAL THICKNESS: Selection of sheet metal of proper thickness is necessary to maintain strength while firing and in service. Unfortunately, no absolute rules can be given for proper thickness. For most appliance sheet-metal parts thicknesses range from 0.030 to 0.050-inch, but the selection depends on size of the part, enamel thickness, mechanical strength and rigidity needed, and mechanical strength added by embossing, flanges or stiffeners.

COATING STRENGTH: Components should be designed to utilize the mechanical strength properties of enamel to the utmost. Porcelain enamel is much stronger in compression than in tension and, if possible, the part should be designed so that applied loads or impact place the enamel in compression.

Thickness, too, is important in determining strength, impact resistance and resistance to chipping of the coating. As previously discussed (see *Resistance to Chipping*, preceding article), most effort has been devoted to obtaining thin coatings which can flex when metal is distorted by impact. As coating thickness



Drying oven has inside and outside walls made from porcelain enameled panels. Easily cleaned, the coating resists relatively high temperatures and atmospheric corrosion.

Photo, courtesy Vitreous Steel Products Co.

increases, stiffness of the underlying structure must be increased to resist flexure, and a heavier gage metal is usually required. Porcelain-enamel coatings on the edges or corners of parts are more subject to chipping than coatings on flat areas. Therefore, radii on corners and edges should be as large as possible.

Removing the cover coat by brushing is frequently employed to reduce enamel thickness at critical areas on sheet-metal parts, where the normal thickness of enamel might not flex enough to withstand chipping.

STAMPING, FORMING AND DRAWING: Prevention of internal strains in the metal is one of the cardinal recommendations for stamped parts, since release of internal strains during firing or while in service can cause hairlining, fishscaling and pop-off of the enamel. Metal should not be worked to its endurance limit, and return flanges should be avoided if possible.

Design should be such that forming and drawing operations work the metal from the center toward the outside edge, thus avoiding "loose" metal in the center of parts which are rim-bound. This excess metal may warp during firing, causing a bulge or "oil-can effect" on flat areas. If excess or loose metal cannot be avoided, the use of embosses or a heavier stock should be considered.

Shearing, stamping or punching operations should be performed perpendicular to the plane of the metal, so that the metal edge is square and not sharp. This consideration will usually involve stamping and punching holes, cutouts, etc., before forming or drawing, and the part should, if possible, be designed for this sequence of operations. Parts are often designed to permit punching or stamping toward the back or reverse side of the component, so that any burr extruded during stamping will be in a noncritical position.

WELDING: Gas or electric welding can be used on porcelain-enameled parts. Strips of the parent metal are usually employed as filler metal or electrodes on sheet-metal parts, and welds must be thick enough to develop the full strength of the adjacent metal. Brazing is not normally used, since an enamel for ferrous metal will not adhere to the brazing metal.

Welds should be placed on flat areas, at tangent points of edge arcs, or adjacent to the development of any formed or drawn shape so that they can be easily ground and inspected. Where practical, welds should be made from the reverse or back side of the part, although metal must run through the joint to make the surface flush. If so placed, the weld may not have to be ground. For the previous reasons and to avoid sharp corners, welds should not be placed at corners, but if so placed they should be peened.

Hairlining may be caused by spacing spot welds too far apart, by overlapping parts, by double thicknesses, and by warpage of the metal due to localized heat.

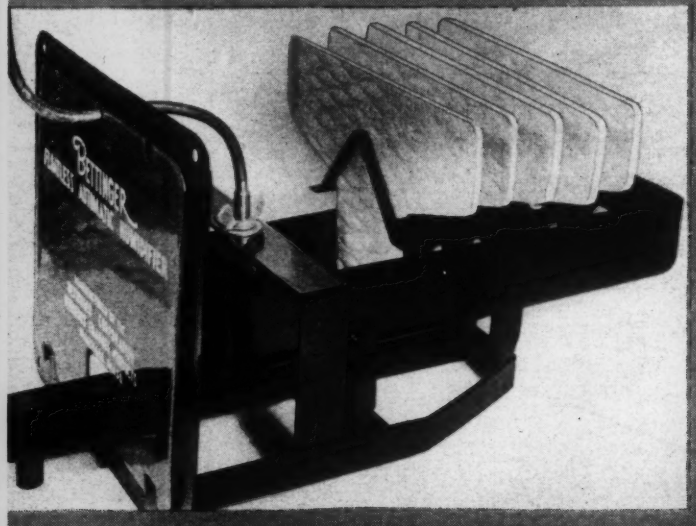
ASSEMBLY: Sometimes parts for porcelain enameling can be combined into a one-piece assembly and enameled at the same time. The same considerations apply as in enameling single components, except that more careful attention should be given to support of the assembly and even distribution of metal. Corners should be strengthened, possibly by using gussets. Welded attachments should be avoided, as should restriction of uniform expansion and contraction of large areas by the welded joints. Supports should be designed to distribute loads evenly.

Provision should be made in any assembly design for spacers or other means of separating adjacent porcelain-enameled parts to minimize the possibility of chipping. The creation of uneven stresses in assembly must be avoided, so spacers must be uniformly thick. Washers, sometimes felt or asbestos-backed, under bolt or fastener heads assist in distributing the load over the underlying enamel surface.

Summary: In any vitreous-enameled component, as in any well-designed part, the interrelation of three primary factors must always be kept in mind. First is the selection of an enamel and base metal—the materials from which the part will be made; second, consideration of the processing variables which, in porcelain enameling, require special attention; third, formulation of a design which adequately integrates these two factors and, additionally, "gets the most" from the vitreous coating.

All metal parts except the valve system are porcelain enameled in this warm-air furnace humidifier. Porcelain on steel gives the double advantage of being rust and corrosion-proof under rather exacting conditions, and of replacing more expensive and scarcer metals.

Photo, courtesy Bettinger Corp.



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Gear Ratio Logarithms

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Part 1–Combinations of 16 to 120 Teeth

SELECTION of gear pairs or trains to give a certain speed ratio can be easily accomplished by mental calculation when the ratio is in low whole numbers, such as 2 to 1 or 5 to 4. But when the required ratios are not simple, a more involved procedure must be employed. Two types of methods are available for determining the number of teeth to produce the desired ratio or a sufficiently accurate approximation. Calculation methods, such as the use of continuing fractions, may be employed or gear ratio logarithms may be used. Generally, results can be obtained more quickly with gear logs, if tables with an adequate tooth number range are available. In this and a succeeding article such tables are presented with examples demonstrating their applications to gearing calculations.

Gear log is the term applied to the logarithm of a gear ratio—the logarithm of the number corresponding to the ratio of the numbers of teeth in a pair of gears. TABLE 1 in this issue is a sequential compilation of the common logarithms of the ratios obtained from combinations of the numbers 16 to 120. This range covers numbers of gear teeth applicable to the majority of machinery drives. All ratios such as 2/1 or 3/1 appear in the table in that form. The logarithm of the ratio applies, of course, to all gear pairs of this ratio regardless of the total number of teeth in each gear. Other ratios are expressed with the minimum number of teeth consistent with the stated scope of the table. For example, 0.0791813 is listed as the log of 24/20 but the logarithm is the same for all gears whose teeth are in the ratio of 6/5, such as 120/100, 96/80, etc.

To appear in the next issue, TABLE 2 is an extension of TABLE 1 and includes the logarithms of ratios obtained by use of the numbers 121 to 150 inclusive.

As an example, the ratio of the circumference to the diameter of a circle, π, will be used to demonstrate application of TABLE 1. The various values most often accepted for π and their common logarithms, or logarithms to the base 10, are:

1. To eight decimal places, log 3.14159265 = 0.4971499
2. To four decimal places, log 3.1416 = 0.4971509
3. To three decimal places, log 3.142 = 0.4972062
4. Common approximation, log 3 1/7 = log 3.142857 = 0.4973247

Some of the solutions for π to be presented are depicted in *Fig.* 1.

Single Ratio: To find the pair of gears which most accurately produce a given ratio, find the logarithm of the ratio and then from the table select the pair of gears whose logarithm is nearest to the log of the desired ratio. With π as the desired ratio, gears having 88 and 28 teeth yield a ratio exactly equal to 3 1/7. No other two gears from TABLE 1 more exactly produce the ratio π. For certain applications these gears might provide a sufficiently accurate approximation. If greater accuracy is required, a multiple-ratio combination must be used.

Two-Ratio Combinations: Since the possible two-ratio combinations are numerous, a plan for their selection from the tables is not essential to achieve accuracy to the fifth digit of the log of the desired overall ratio. However, when the purpose of the drive is to reduce speed, gear velocities in general are reduced by selection of a first reduction ratio that performs the greater portion of the total reduction. To apply this plan, first select the second reduction ratio from the low end of the table. Subtract this log from the log of the desired final ratio to obtain the log of the required first reduction ratio. For example,

log 3.14159265 = 0.4971499
− log 120/119 (second reduction) = 0.0036342
log of required first reduction = 0.4935157

Then, by inspection of TABLE 1, find the ratio with a

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logarithm closest to 0.4975157: log 81/26 = 0.4935117. As a check,

$$\left(\frac{120}{119}\right)\left(\frac{81}{26}\right) = 3.1415901$$

The table may be used in this fashion for compilation of a series of solutions in a short time. The best answer from the standpoint of required accuracy or preferred numbers of teeth may then be chosen.

A different approach would be preferable if the drive were to be reversible and have the same input speed in either case. Then, a first ratio which is approximately the square root of the overall ratio should be selected. The log of such a ratio, of course, is

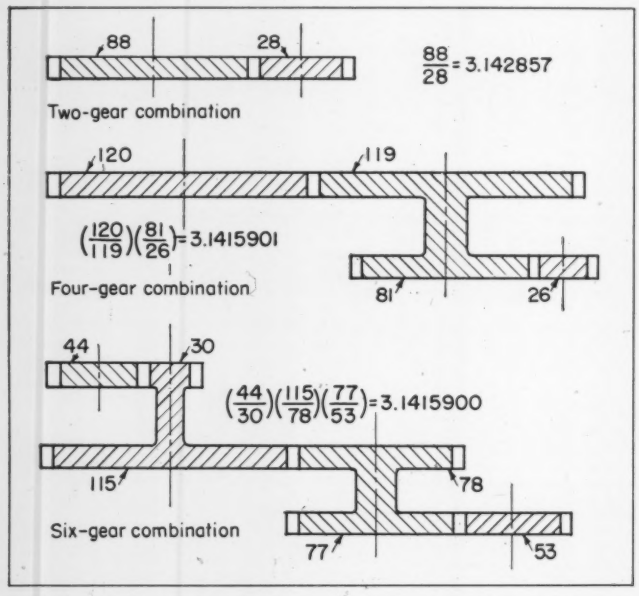


Fig. 1—Various Methods for obtaining gear ratio approximations of π

approximately one-half that of the log of the desired final ratio. This method is not as likely to produce as high an accuracy for π as the previous method because one-half the log of π does not fall within that region of the table where the logarithmic increments are small. However, when half the log of the final ratio does fall in such an area, high accuracy is obtained.

Another approach, which doubles the available four-gear combinations is to reverse the driver-driven relationship of one of the selected component ratios. The reduction of one pair of gears is then overlapped by the second pair. To apply this approach, first choose the log of a low ratio from the table, add this log to the log of the required final ratio, and then find the ratio in the table whose log is closest to this sum. For example

log of 67/66 = 0.0065309
+ log of 3.14159265 = 0.4971499
log of required second ratio = 0.5036808

From TABLE 1, the nearest answer is log 118/37 = 0.5036803. Then, inverting the first ratio and checking,

$$\left(\frac{66}{67}\right)\left(\frac{118}{37}\right) = 3.1415894$$

Random selection of logarithms for extremely accurate solutions is made easier by selection of one ratio from such a range as to place the other within an area of the table where the increment is small. Such areas precede or follow the integer ratios such as 1/1, 2/1, etc. This method combined with the immediately preceding procedure produces combinations giving an extremely accurate value of π:

log 3.14159265 = 0.4971499
+ log 113/90 = 0.0988359
log of required second reduction = 0.5959858

From TABLE 1, log 71/18 = 0.5959858. As a check,

$$\left(\frac{90}{113}\right)\left(\frac{71}{18}\right) = 3.14158292$$

The difference between this answer and the most accurate value of π is 27×10^{-8}. More accurate results cannot be obtained with seven-place log tables. This solution, by cancellation, produces the two-gear combination of 355/113 which could be used if design conditions permit the use of such fine-pitch gears.

Three-Ratio Combinations: Several circumstances may preclude satisfactory two-ratio solutions. Difficulties might arise because of a fixed initial driver, final driven gear size, or a ratio so high that both ratios of a four-gear combination fall in a large-increment region. The table may then be used to choose a six-gear combination. One such solution is:

log 44/30 = 0.1663314
+ log 115/78 = 0.1686032
log (44/30) (115/78) = 0.3349346

log 3.14159265 = 0.4971499
− log (44/30) (115/78) = 0.3349346
log of third ratio = 0.1622153

From TABLE 1, log 77/53 = 0.1622148. The check shows

$$\left(\frac{44}{30}\right)\left(\frac{115}{78}\right)\left(\frac{77}{53}\right) = 3.1415900$$

Although π has been used throughout these examples, and extreme accuracy has been achieved in some instances, the gear log tables are just as useful for other ratios and for drives not requiring this accuracy. Utility of this method of obtaining gear ratios will be increased by a second table to be published next month. Ratios with gear teeth from 121 to 150 will be covered.

Table 1—Gear Ratio Logarithms for Numbers from 16 to 120

Ratio	Log	Ratio	Log	Ratio	Log	Ratio	Log	Ratio	Log	Ratio	Log	Ratio	Log
120/16	.8750612	98/17	.7607772	92/18	.7085153	97/21	.6645524	81/19	.6297314	87/22	.5970966	78/21	.5698753
119/16	.8714270	92/16	.7596678	97/19	.7080181	120/26	.6642079	98/23	.6294983	83/21	.5968588	115/31	.5693361
118/16	.8677620	109/19	.7586729	102/20	.7075702	83/18	.6638056	115/27	.6293340	79/20	.5965971	89/24	.5691788
117/16	.8640657	103/18	.7575647	107/21	.7071643	106/23	.6635781	68/16	.6283889	75/19	.5963077	63/17	.5688916
116/16	.8603380	120/21	.7569619	112/22	.7067953	92/20	.6627578	106/25	.6273659	71/18	.5959858	100/27	.5686362
115/16	.8565778	114/20	.7558749	117/23	.7064579	101/22	.6618987	89/21	.6271707	67/17	.5956259	74/20	.5682017
114/16	.8527849	91/16	.7549214	81/16	.7043650	78/17	.6616457	72/17	.6268836	63/16	.5952205	85/23	.5676911
113/16	.8489584	108/19	.7546702	86/17	.7040496	110/24	.6611815	110/26	.6264194	118/30	.5947607	96/26	.5672979
120/17	.8487323	102/18	.7533277	91/18	.7037689	87/19	.6607657	93/22	.6260602	114/29	.5945069	107/29	.5669858
7/1	.8450980	113/20	.7520484	96/19	.7035176	119/26	.6605737	76/18	.6255411	110/28	.5942347	118/32	.5667320
118/17	.8414331	96/17	.7518223	101/20	.7032914	96/21	.6600519	97/23	.6250439	106/27	.5939421	70/19	.5663444
111/16	.8412030	107/19	.7506302	106/21	.7030866	105/23	.6594615	118/28	.6247240	102/26	.5936269	81/22	.5660623
117/17	.8377368	90/16	.7501225	111/22	.7029003	73/16	.6592029	80/19	.6243364	98/25	.5932861	92/25	.5658478
110/16	.8372727	118/21	.7496627	116/23	.7027302	114/25	.6589649	101/24	.6241102	94/24	.5929167	103/28	.5656792
116/17	.8340091	101/18	.7490489	5/1	.6989700	82/18	.6585414	84/20	.6232493	90/23	.5925147	114/31	.5655432
109/16	.8333065	112/20	.7481880	119/24	.6953358	91/20	.6580114	109/26	.6224532	86/22	.5920758	66/18	.5642714
115/17	.8302489	95/17	.7472747	114/23	.6951771	100/22	.6575773	88/21	.6222634	82/21	.5915946	117/32	.5630357
108/16	.8293038	106/19	.7465523	109/22	.6950038	109/24	.6572153	67/16	.6219548	78/20	.5910646	106/29	.5629079
114/17	.8264560	117/21	.7459666	104/21	.6948140	118/26	.6569087	113/27	.6217146	113/29	.5906804	95/26	.5627503
107/16	.8252638	89/16	.7452700	99/20	.6946052	77/17	.6560418	92/22	.6213651	74/19	.5904781	84/23	.5625515
120/18	.8239087	100/18	.7447275	94/19	.6943743	86/19	.6557449	117/28	.6210277	109/28	.5902685	73/20	.5622929
113/17	.8226295	111/20	.7442930	113/23	.6913506	95/21	.6555043	71/17	.6208094	70/18	.5898255	62/17	.5619428
106/16	.8211859	94/17	.7426790	89/18	.6941175	104/23	.6553055	96/23	.6205434	101/26	.5893481	113/31	.5617167
119/18	.8202745	105/19	.7424357	84/17	.6938304	113/25	.6551384	75/18	.6197888	66/17	.5890950	102/28	.5614422
112/17	.8187691	116/21	.7422387	79/16	.6935071	72/16	.6532125	104/25	.6190933	97/25	.5888317	91/25	.5611014
105/16	.8170693	88/16	.7403627	118/24	.6916708	112/25	.6512780	79/19	.6188735	62/16	.5882717	80/22	.5606673
118/18	.8166095	115/21	.7384783	108/22	.6910011	103/23	.6511094	108/26	.6184505	120/31	.5878295	109/30	.5603052
111/17	.8148741	104/19	.7382797	103/21	.6906179	94/21	.6509086	83/20	.6180481	89/23	.5876622	69/19	.5600955
104/16	.8129133	93/17	.7380340	98/20	.6901961	85/19	.6506653	112/27	.6178542	116/30	.5873367	98/27	.5598623
110/17	.8109438	109/20	.7369650	93/19	.6897293	76/17	.6503647	87/21	.6173000	85/22	.5869962	87/24	.5593081
116/18	.8091855	120/22	.7367585	88/18	.6892102	116/26	.6494847	120/29	.6167832	112/29	.5868200	105/29	.5587913
103/16	.8087172	98/18	.7359536	83/17	.6886292	107/24	.6491726	91/22	.6166187	81/21	.5862657	76/21	.5585943
109/17	.8069776	87/16	.7353993	78/16	.6879746	98/22	.6488034	95/23	.6159958	104/27	.5856695	94/26	.5581546
115/18	.8054253	114/21	.7346856	112/23	.6874902	89/20	.6483600	66/16	.6154239	77/20	.5854607	112/31	.5578563
102/16	.8044802	103/19	.7340836	107/22	.6869611	80/18	.6478175	103/25	.6148972	100/26	.5850267	65/18	.5576409
108/17	.8029749	92/17	.7333389	102/21	.6863809	111/25	.6473830	70/17	.6146491	73/19	.5845693	83/23	.5573503
114/18	.8016324	119/22	.7331243	97/20	.6857417	71/16	.6471383	107/26	.6144105	96/25	.5843312	101/28	.5571634
120/19	.8004276	108/20	.7323938	92/19	.6850342	102/23	.6468724	111/27	.6139592	119/31	.5841853	119/33	.5570331
101/16	.8002014	97/18	.7314992	87/18	.6842468	93/21	.6462636	115/28	.6135498	69/18	.5835766	72/20	.5563025
107/17	.7989349	113/21	.7308591	111/23	.6835952	115/26	.6457245	78/19	.6133410	111/29	.5829250	115/32	.5555478
113/18	.7978059	86/16	.7303785	82/17	.6833650	84/19	.6455257	119/29	.6131490	88/23	.5827549	97/27	.5554079
119/19	.7967934	102/19	.7298466	106/22	.6828832	106/24	.6450947	82/20	.6127839	65/17	.5824645	79/22	.5552044
100/16	.7958800	118/22	.7294593	77/16	.6823707	75/17	.6446124	86/21	.6122792	107/28	.5822258	61/17	.5548809
106/17	.7948570	91/17	.7285925	101/21	.6821021	97/22	.6443490	90/22	.6118198	84/22	.5818566	104/29	.5546353
112/18	.7939455	107/20	.7283538	96/20	.6812412	119/27	.6441832	94/23	.6114001	103/27	.5814734	86/24	.5542873
118/19	.7931284	112/21	.7269987	115/24	.6804856	88/20	.6434527	98/24	.6110149	61/16	.5812198	111/31	.5539613
99/16	.7915152	117/22	.7257630	91/19	.6802878	101/23	.6425936	102/25	.6106602	80/21	.5808707	68/19	.5537553
105/17	.7907404	101/19	.7255678	110/23	.6796649	79/18	.6423546	106/26	.6103326	99/26	.5806619	93/26	.5535096
111/18	.7900505	85/16	.7252985	86/18	.6792260	114/26	.6419316	110/27	.6100289	118/31	.5805203	118/33	.5533681
98/16	.7871061	106/20	.7242759	105/22	.6787666	92/21	.6415685	114/28	.6097469	76/20	.5797836	75/21	.5528420
104/17	.7865844	90/17	.7237936	81/17	.6780361	70/16	.6409780	118/29	.6094840	110/29	.5789947	107/30	.5522625
110/18	.7861202	111/21	.7231037	100/21	.6777807	118/27	.6405182	65/16	.6087934	91/24	.5788302	82/23	.5520861
116/19	.7857044	95/18	.7224511	119/25	.6776070	83/19	.6403245	69/17	.6084002	72/19	.5785789	114/32	.5517549
97/16	.7826517	116/22	.7220353	109/23	.6756987	96/22	.6398485	73/18	.6080504	106/28	.5781475	89/25	.5514500
103/17	.7823883	100/19	.7212464	90/19	.6754889	109/25	.6394865	77/19	.6077371	87/23	.5777915	64/18	.5509075
109/18	.7821540	84/16	.7201593	104/22	.6746106	74/17	.6387828	81/20	.6074550	68/18	.5772364	103/29	.5504392
115/19	.7819442	110/21	.7191734	85/18	.6741464	87/20	.6384893	85/21	.6071996	117/31	.5768240	71/20	.5502283
6/1	.7781513	89/17	.7189411	118/25	.6739420	100/23	.6382722	89/22	.6069673	83/22	.5766554	110/31	.5500310
119/20	.7745170	115/22	.7182751	99/21	.6734159	113/26	.6381051	93/23	.6067551	98/26	.5762528	78/22	.5496719
113/19	.7743248	94/18	.7178554	113/24	.6728676	78/18	.6368221	97/24	.6065605	113/30	.5759571	85/24	.5492067
107/18	.7741113	120/23	.7174534	80/17	.6726411	108/25	.6354838	101/25	.6063814	64/17	.5757311	92/26	.5488145
101/17	.7738725	99/19	.7168816	94/20	.6720979	95/22	.6353009	105/26	.6062160	79/21	.5754078	99/28	.5484772
95/16	.7736036	109/21	.7152072	108/23	.6716960	82/19	.6350603	109/27	.6060627	94/25	.5751879	106/30	.5481846
112/19	.7704644	83/16	.7149581	75/16	.6709413	69/16	.6347291	113/28	.6059204	109/29	.5750285	113/32	.5479284
106/18	.7700334	114/22	.7144822	89/19	.6706364	112/26	.6342447	117/29	.6057877	60/16	.5740313	120/34	.5477023
100/17	.7695511	88/17	.7140338	103/22	.6704145	99/23	.6339074	116/23	.6027302	116/31	.5730963	67/19	.5473212
94/16	.7690079	119/23	.7138192	117/25	.6702457	86/20	.6334685	4/1	.6020600	86/23	.5727707	74/21	.5470124
117/20	.7671557	93/18	.7132104	84/18	.6690068	116/27	.6330942	119/30	.5984257	71/19	.5725047	81/23	.5467572
111/19	.7665694	98/19	.7124725	107/23	.6676560	73/17	.6328740	115/29	.5982998	112/30	.5720967	88/25	.5465427
105/18	.7659168	103/20	.7118072	93/20	.6674329	103/24	.6326260	111/28	.5981650	97/26	.5717984	95/27	.5463598
99/17	.7651853	108/21	.7112045	79/17	.6671782	90/21	.6320232	107/27	.5980200	82/22	.5713912	102/29	.5462022
93/16	.7643629	113/22	.7106557	116/25	.6665180	107/25	.6314438	103/26	.5978639	108/29	.5710258	109/31	.5460648
116/20	.7634280	118/23	.7105442	102/22	.6661775	77/18	.6312182	99/25	.5976952	67/18	.5708023	56/16	.5440680
110/19	.7626391	82/16	.7096939	88/19	.6657391	94/22	.6307052	95/24	.5975124	93/25	.5705429	115/33	.5421839
104/18	.7617608	87/17	.7090704	74/16	.6651117	111/26	.6303497	91/23	.5973136	119/32	.5703970	108/31	.5420621

GEAR LOGS .5419224 TO .3727232

Ratio	Log	Ratio	Log	Ratio	Log	Ratio	Log	Ratio	Log	Ratio	Log	Ratio	Log
101/29	.5419224	111/34	.5138441	86/28	.4873405	55/19	.4616091	115/42	.4374485	96/37	.4140695	79/32	.3924771
87/25	.5415793	62/19	.5136381	89/29	.4869920	81/28	.4613270	52/19	.4372497	83/32	.4139281	116/47	.3923601
80/23	.5413622	75/23	.5133335	92/30	.4866655	107/37	.4611821	93/34	.4370040	70/27	.4137343	74/30	.3921114
73/21	.5411036	88/27	.5131189	95/31	.4863619	78/27	.4607308	82/30	.4366926	57/22	.4134522	106/43	.3918374
66/19	.5407903	101/31	.5129597	49/16	.4860761	101/35	.4602534	112/41	.4364341	101/39	.4132567	69/28	.3916911
118/34	.5404031	114/35	.5128369	101/33	.4858075	75/26	.4600880	71/26	.4362850	44/17	.4130038	101/41	.3915375
111/32	.5401730	52/16	.5118834	52/17	.4855544	49/17	.4597472	101/37	.4361197	119/46	.4127892	64/26	.3912067
104/30	.5399120	120/37	.5109795	107/35	.4853158	72/25	.4593925	60/22	.4357286	75/29	.4126633	91/37	.3908397
97/28	.5396137	107/33	.5108699	55/18	.4850902	95/33	.4592097	109/40	.4353665	106/41	.4125220	59/24	.3906408
90/26	.5392692	94/29	.5107299	113/37	.4848767	118/41	.4590981	79/29	.4352291	62/24	.4121805	86/35	.3904305
83/24	.5388669	81/25	.5105450	58/19	.4846744	69/24	.4586379	49/18	.4349236	111/43	.4118545	113/46	.3903206
76/22	.5383909	68/21	.5102896	119/39	.4844824	112/39	.4581534	117/43	.4347172	80/31	.4117283	54/22	.3899711
107/31	.5380221	110/34	.5099138	61/20	.4842998	89/31	.4580283	87/32	.4343693	49/19	.4114425	103/42	.3895879
69/20	.5378191	97/30	.5096504	64/21	.4839607	66/23	.4578161	106/39	.4342413	116/45	.4112455	76/31	.3894519
100/29	.5376020	84/26	.5093060	67/22	.4836521	109/38	.4576429	57/21	.4336556	67/26	.4111015	49/20	.3891661
62/18	.5371192	113/35	.5090104	70/23	.4833702	86/30	.4573772	103/38	.4330536	85/33	.4109050	120/49	.3889851
117/34	.5367068	71/22	.5088356	73/24	.4831117	106/37	.4571042	84/31	.4329176	103/40	.4107772	71/29	.3888603
86/25	.5365585	100/31	.5086383	76/25	.4828736	63/22	.4569178	65/24	.4327012	54/21	.4101746	93/38	.3886993
55/16	.5362427	87/27	.5081555	79/26	.4826538	83/29	.4566801	111/41	.4325391	113/44	.4096257	115/47	.3885999
79/23	.5358993	103/32	.5076872	82/27	.4824501	103/36	.4565347	46/17	.4323089	95/37	.4095219	66/27	.3881801
103/30	.5357159	74/23	.5075039	85/28	.4822609	60/21	.4559320	119/44	.4320943	77/30	.4093694	105/43	.3877207
72/21	.5351132	119/37	.5073453	88/29	.4820847	117/41	.4554018	62/23	.4306639	59/23	.4091242	83/34	.3875992
113/33	.5345645	90/28	.5070845	91/30	.4819201	97/34	.4552928	73/27	.4319591	100/39	.4089354	61/25	.3873898
89/26	.5344167	106/33	.5067920	94/31	.4817662	77/27	.4551269	100/37	.4317983	41/16	.4086639	100/41	.3872161
65/19	.5341598	61/19	.5065752	97/32	.4816217	57/20	.4548449	54/20	.4313638	105/41	.4084054	39/16	.3869446
106/31	.5339442	77/24	.5062795	100/33	.4814861	94/33	.4546140	116/43	.4309895	64/25	.4082400	95/39	.3866590
82/24	.5336027	93/29	.5060849	103/34	.4813583	74/26	.4542584	89/33	.4308761	87/34	.4080404	56/23	.3864602
99/29	.5332372	109/34	.5059476	106/35	.4812379	91/32	.4538914	97/36	.4304692	110/43	.4079242	73/30	.3862016
116/34	.5329791	64/20	.5051500	109/36	.4811240	71/25	.4533183	70/26	.4301247	46/18	.4074853	90/37	.3860408
75/22	.5326386	115/36	.5043953	112/37	.4810163	88/31	.4531210	113/42	.4298291	97/38	.4069881	51/21	.3853509
92/27	.5324240	99/31	.5042735	115/38	.4809142	105/37	.4529876	78/29	.4296966	74/29	.4068337	114/47	.3848070
109/32	.5322765	83/26	.5041047	118/39	.4808174	51/18	.4522967	59/22	.4284293	51/20	.4065402	97/40	.3847117
68/20	.5314789	67/21	.5038555	3/1	.4771213	116/41	.4516741	43/16	.4293485	79/31	.4062654	80/33	.3845761
112/33	.5307041	118/37	.5036803	119/40	.4734870	99/35	.4515672	94/35	.4290599	107/42	.4061345	63/26	.3843672
95/28	.5305656	51/16	.5034502	116/39	.4733934	82/29	.4514159	51/19	.4288166	56/22	.4057653	109/45	.3842140
78/23	.5303664	86/27	.5031347	113/38	.4732948	65/23	.4511856	110/41	.4286088	117/46	.4054281	46/19	.3840042
61/18	.5300573	70/22	.5026753	110/37	.4731910	113/40	.4510184	67/25	.4281348	89/35	.4053220	75/31	.3836996
105/31	.5298276	89/28	.5022320	107/36	.4730813	48/17	.4507923	75/28	.4279033	61/24	.4051186	104/43	.3835648
88/26	.5295093	54/17	.5019449	104/35	.4729653	79/28	.4504691	83/31	.4277164	94/37	.4049262	58/24	.3832168
115/34	.5292189	73/23	.5015951	101/34	.4728425	110/39	.4503281	91/34	.4275625	66/26	.4045706	99/41	.3828513
71/21	.5290390	92/29	.5013898	98/33	.4727122	62/22	.4499690	99/37	.4274335	104/41	.4042494	70/29	.3827000
98/29	.5288281	111/35	.5012550	95/32	.4725736	107/38	.4496002	107/40	.4273238	71/28	.4041003	111/46	.3825652
81/24	.5282738	57/18	.5006024	92/31	.4724261	76/27	.4494498	115/43	.4272293	109/43	.4039580	41/17	.3823359
118/35	.5278140	98/31	.4998654	89/30	.4722687	45/16	.4490925	56/21	.4259687	76/30	.4036923	94/39	.3820633
91/27	.5276776	79/25	.4496871	86/29	.4721005	104/37	.4488316	117/44	.4247332	119/47	.4034491	53/22	.3818532
64/19	.5274264	60/19	.4993976	83/28	.4719201	59/21	.4486327	109/41	.4246426	81/32	.4033350	118/49	.3816859
101/30	.5272001	101/32	.4991714	80/27	.4717262	73/26	.4483496	101/38	.4245378	91/36	.4027389	65/27	.3815496
74/22	.5268002	82/26	.4988406	77/26	.4715174	87/31	.4481576	93/35	.4244149	48/19	.4024876	77/32	.3813407
84/25	.5263393	104/33	.4985194	74/25	.4712917	101/36	.4480189	85/32	.4242689	101/40	.4022614	89/37	.3811883
94/28	.5259699	63/20	.4983105	71/24	.4710471	115/41	.4479139	77/29	.4240927	53/21	.4020566	101/42	.3810721
104/31	.5256716	85/27	.4980551	68/23	.4707811	56/20	.4471580	69/26	.4238758	111/44	.4018703	113/47	.3809805
114/34	.5254260	107/34	.4979049	65/22	.4704907	109/39	.4463619	61/23	.4236020	58/23	.4017002	48/20	.3802112
67/20	.5250448	88/28	.4973247	62/21	.4701714	95/34	.4462447	114/43	.4234364	63/25	.4014005	115/48	.3794566
77/23	.5247629	113/36	.4967759	59/20	.4698220	81/29	.4460870	53/20	.4232459	68/27	.4011451	103/43	.3793687
87/26	.5245460	91/29	.4966434	115/39	.4696332	67/24	.4458636	98/37	.4230244	73/29	.4009249	91/38	.3792578
97/29	.5243737	69/22	.4964264	56/19	.4694344	120/43	.4457127	45/17	.4227636	78/31	.4007329	79/33	.3791132
107/32	.5242338	116/37	.4962563	109/37	.4692248	106/38	.4455223	82/31	.4224522	83/33	.4005642	67/28	.3789168
117/35	.5241177	94/30	.4960066	53/18	.4690034	92/33	.4452739	119/45	.4223345	88/35	.4004147	55/23	.3786349
60/18	.5228798	119/38	.4957634	103/35	.4687692	78/28	.4449366	74/28	.4220737	93/37	.4002812	98/41	.3784422
113/34	.5215995	72/23	.4956047	50/17	.4685211	103/37	.4446355	103/39	.4217726	98/39	.4001615	43/18	.3781960
103/31	.5214755	97/31	.4954100	97/33	.4682578	64/23	.4444522	95/36	.4214211	103/41	.4000533	117/49	.3779898
93/28	.5213249	75/24	.4948501	47/16	.4679799	89/32	.4442400	58/22	.4210063	108/43	.3999553	74/31	.3778700
83/25	.5211381	103/33	.4943233	91/31	.4676797	114/41	.4441210	108/41	.4206399	113/45	.3998659	105/44	.3777366
73/22	.5209002	78/25	.4941546	88/30	.4673614	75/27	.4436975	79/30	.4205058	118/47	.3997841	62/26	.3774184
63/19	.5205869	53/17	.4938270	85/29	.4670209	111/40	.4432630	50/19	.4202164	40/16	.3979400	112/47	.3771201
116/35	.5203900	81/26	.4935117	82/28	.4666559	86/31	.4431368	71/27	.4198945	117/47	.3960878	81/34	.3770061
106/32	.5201559	109/35	.4933585	120/41	.4663973	61/22	.4429071	92/35	.4197198	112/45	.3960055	50/21	.3767507
96/29	.5198732	56/18	.4929155	79/27	.4662633	97/35	.4427037	113/43	.4196099	107/43	.3959153	119/50	.3765770
86/26	.5195252	115/37	.4924961	117/40	.4661257	72/26	.4423592	42/16	.4191293	102/41	.3958163	69/29	.3764511
119/36	.5192445	87/28	.4923613	76/26	.4658403	119/43	.4420785	97/37	.4185700	97/39	.3957071	88/37	.3762810
76/23	.5190858	59/19	.4920984	111/38	.4655394	83/30	.4419568	76/29	.4184156	92/37	.3955861	107/45	.3761713
109/33	.5189126	90/29	.4918445	73/25	.4653829	47/17	.4416490	55/21	.4181434	87/35	.3954513	38/16	.3756637
66/20	.5185139	62/20	.4913617	108/37	.4652221	105/38	.4414057	89/34	.4179111	82/33	.3953000	102/43	.3751317
89/27	.5180262	96/31	.4909095	70/24	.4648868	58/21	.4412087	68/26	.4175356	77/31	.3951290	83/35	.3750101
56/17	.5177391	65/21	.4906941	102/35	.4645322	80/29	.4406980	115/44	.4172451	72/29	.3949345	64/27	.3748162
79/24	.5174159	99/32	.4904852	67/23	.4643470	91/33	.4405275	81/31	.4171233	67/27	.3947110	109/46	.3746687
102/31	.5172395	68/22	.4900862	99/34	.4641563	102/37	.4403985	47/18	.4168254	62/25	.3944517	45/19	.3744589
69/21	.5166298	105/34	.4897104	64/22	.4637573	113/41	.4402945	107/41	.4165999	119/48	.3943058	116/49	.3742619
105/32	.5160393	71/23	.4895305	93/32	.4633329	77/28	.4393327	60/23	.4164235	57/23	.3941471	71/30	.3741370
82/25	.5158739	108/35	.4893558	61/21	.4631105	118/43	.4384135	73/28	.4161649	109/44	.3939580	97/41	.3739878
59/18	.5155795	74/24	.4890205	90/31	.4628808	107/39	.4383192	86/33	.4159846	52/21	.3937840	52/22	.3735806
95/29	.5153256	114/37	.4887032	119/41	.4627631	96/35	.4382032	99/38	.4158516	99/40	.3935752	111/47	.3732251
72/22	.5149098	77/25	.4885507	58/20	4623980	85/31	.4380572	112/43	.4157495	47/19	.3933443	85/36	.3731164
85/26	.5144456	117/38	.4884021	113/39	.4620138	74/27	.4378679	52/20	.4149733	89/36	.3930875	59/25	.3729120
98/30	.5141048	83/27	.4877143	84/29	.4618813	63/23	.4376127	109/42	.4141772	42/17	.3928004	92/39	.3727232

GEAR LOGS .3723859 TO .2488520

Ratio	Log	Ratio	Log	Ratio	Log	Ratio	Log	Ratio	Log	Ratio	Log	Ratio	Log
66/28	.3723859	115/51	.3531276	114/53	.3326290	97/47	.3146738	83/42	.2958288	103/54	.2804434	90/49	.2640464
106/45	.3720934	36/16	.3521725	43/20	.3324385	33/16	.3143939	81/41	.2957011	82/43	.2803454	101/55	.2639587
73/31	.3719612	119/53	.3512711	101/47	.3322235	101/49	.3141253	79/40	.2955671	61/32	.2801798	112/61	.2638882
113/48	.3718372	110/49	.3511966	58/27	.3320642	68/33	.3139950	77/39	.2954262	101/53	.2800455	33/18	.2632414
40/17	.3716111	101/45	.3511089	73/34	.3318440	103/50	.3138672	75/38	.2952777	40/21	.2798407	119/65	.2626336
87/37	.3713176	92/41	.3510039	88/41	.3316988	35/17	.3136191	73/37	.2951212	99/52	.2796319	108/59	.2625718
47/20	.3710679	83/37	.3508764	103/48	.3315960	107/52	.3133805	71/36	.2949558	59/31	.2794903	97/53	.2624958
101/43	.3708529	74/33	.3507178	118/55	.3315193	72/35	.3132845	69/35	.2947811	78/41	.2793107	86/47	.2624006
54/23	.3706660	65/29	.3505154	45/21	.3309932	109/53	.3131506	67/34	.2945959	97/51	.2792015	75/41	.2622774
115/49	.3705017	56/25	.3502480	107/50	.3304138	37/18	.3129292	65/33	.2943995	116/61	.2791282	64/35	.2621120
61/26	.3703565	103/46	.3500794	92/43	.3303193	113/55	.3127157	63/32	.2941905	38/20	.2787536	53/29	.2618779
68/29	.3701109	47/21	.3498786	77/36	.3301882	76/37	.3126119	61/31	.2939679	112/59	.2783660	95/52	.2617203
75/32	.3699113	85/38	.3496353	62/29	.3299937	115/56	.3125098	120/61	.2938514	93/49	.2782868	42/23	.2615215
82/35	.3697459	38/17	.3493347	109/51	.3298553	39/19	.3123110	59/30	.2937307	74/39	.2781671	115/63	.2613573
89/38	.3696064	105/47	.3490914	47/22	.3296752	119/58	.3121190	116/59	.2936060	55/29	.2779647	73/40	.2612629
96/41	.3694873	67/30	.3489535	79/37	.3294154	80/39	.3120254	57/29	.2934769	91/48	.2778002	104/57	.2611584
103/44	.3693845	96/43	.3488027	111/52	.3293197	41/20	.3117539	112/57	.2933431	36/19	.2775489	31/17	.2609128
110/47	.3692948	58/26	.3484547	64/30	.3290587	84/41	.3114954	55/28	.2932032	89/47	.2772921	113/62	.2606867
117/50	.3692157	107/48	.3481426	113/53	.3288025	43/21	.3112492	108/55	.2930611	53/28	.2771179	82/45	.2606014
49/21	.3679768	78/35	.3480266	81/38	.3287014	88/43	.3110142	53/27	.2929121	87/46	.2767615	51/28	.2604122
114/49	.3667088	49/22	.3477734	49/23	.3284683	45/22	.3107898	104/53	.2927584	104/55	.2766706	71/39	.2601937
107/46	.3666260	118/53	.3476061	115/54	.3283040	92/45	.3105753	51/26	.2925969	34/18	.2762064	91/50	.2600714
100/43	.3665315	69/31	.3474874	66/31	.3281822	47/23	.3103701	100/51	.2924298	117/62	.2757940	111/61	.2599932
93/40	.3664229	89/40	.3473300	83/39	.3280135	96/47	.3101733	49/25	.2922561	100/53	.2757241	40/22	.2596373
86/37	.3662968	40/18	.3467875	100/47	.3279021	49/24	.3099849	96/49	.2920751	83/44	.2756254	109/60	.2592752
79/34	.3661482	111/50	.3463530	117/55	.3278230	100/49	.3098039	47/24	.2918867	66/35	.2754759	89/49	.2591939
72/31	.3659708	91/41	.3462575	34/16	.3273590	51/25	.3096302	92/47	.2916899	115/61	.2753680	69/38	.2590655
65/28	.3657554	51/23	.3458424	104/49	.3268372	104/51	.3094631	45/23	.2914847	49/26	.2752228	118/65	.2589686
58/25	.3654880	113/51	.3455082	87/41	.3267354	53/26	.3093026	88/45	.2912702	81/43	.2750165	49/27	.2588323
109/47	.3653286	62/28	.3452337	70/33	.3265841	108/53	.3091479	43/22	.2910458	113/60	.2749271	78/43	.2586261
51/22	.3651475	104/47	.3449354	89/42	.3261407	55/27	.3089939	84/43	.2908108	32/17	.2747011	107/59	.2585318
95/41	.3649397	73/33	.3448090	36/17	.3258536	112/55	.3088553	41/21	.2905646	111/59	.2744710	29/16	.2582780
44/19	.3646991	115/52	.3446945	91/43	.3255729	57/28	.3087169	80/41	.2903061	79/42	.2743773	96/53	.2579953
81/35	.3644170	42/19	.3444957	55/26	.3253894	116/57	.3085831	119/61	.2902172	47/25	.2741579	67/37	.2578731
118/51	.3643118	95/43	.3442551	74/35	.3251637	59/29	.3084540	39/20	.2900346	109/58	.2739985	105/58	.2577613
37/16	.3640817	53/24	.3440647	93/44	.3250144	120/59	.3083292	115/59	.2898458	62/33	.2738778	38/21	.2575643
104/45	.3638208	117/53	.3439100	112/53	.3249421	61/30	.3082085	76/39	.2897490	77/41	.2737068	85/47	.2573210
67/29	.3636768	75/34	.3435824	38/18	.3245111	63/31	.3079788	113/58	.2896504	92/49	.2735917	47/26	.2571246
60/26	.3631780	86/39	.3434339	116/55	.3240953	65/32	.3077634	33/17	.2880650	107/57	.2735089	103/57	.2569623
113/49	.3628823	97/44	.3433190	97/46	.3240139	67/33	.3075609	109/56	.2892385	30/16	.2730013	56/31	.2568263
53/23	.3625481	108/49	.3432277	78/37	.3238929	69/34	.3073702	72/37	.2891308	118/63	.2725415	65/36	.2566109
76/33	.3622997	119/54	.3431532	59/28	.3236940	71/35	.3071903	107/55	.2890211	103/55	.2724745	74/41	.2564478
99/43	.3621667	44/20	.3424227	99/47	.3235373	73/36	.3070204	35/18	.2887955	88/47	.2723848	83/46	.2563203
46/20	.3617278	112/51	.3416478	40/19	.3233064	75/37	.3068596	103/53	.2885613	73/39	.2722583	92/51	.2562176
108/47	.3613259	101/46	.3415636	101/48	.3230802	77/38	.3067071	68/35	.2884409	58/31	2720663	101/56	.2561334
85/37	.3612172	90/41	.3414586	61/29	.3229318	79/39	.3065625	101/52	.2883181	101/54	.2719276	110/61	.2560629
62/27	.3610279	79/36	.3413246	82/39	.3227493	81/40	.3064250	33/17	.2880650	43/23	.2717407	119/66	.2560031
101/44	.3608687	57/26	.3409016	103/49	.3226411	83/41	.3062942	97/50	.2878017	114/61	.2715751	36/20	.2552725
39/17	.3606157	46/21	.3405385	42/20	.3222193	85/42	.3061696	64/33	.2876661	99/53	.2713593	115/64	.2545178
94/41	.3603440	81/37	.3402843	107/51	.3218136	87/43	.3060508	95/49	.2875275	97/52	.2707684	106/59	.2544529
55/24	.3601515	116/53	.3401821	86/41	.3217146	89/44	.3059373	31/16	.2872417	69/37	.2706474	97/54	.2543779
71/31	.3598966	35/16	.3399480	65/31	.3215517	91/45	.3058289	91/47	.2869435	110/59	.2705407	88/49	.2542866
87/38	.3597356	93/43	.3396594	109/52	.3214232	93/46	.3057251	60/31	.2867895	41/22	.2703612	79/44	.2541744
103/45	.3596247	59/27	.3394887	44/21	.3212334	95/47	.3056257	89/46	.2866322	95/51	.2701534	70/39	.2540334
119/52	.3594437	83/38	.3392945	111/53	.3210471	97/48	.3055305	118/61	.2865522	54/29	.2699958	61/34	.2538509
48/21	.3590219	107/49	.3391877	67/32	.3209248	99/49	.3054391	58/30	.2863067	67/36	.2697723	113/63	.2537379
105/46	.3584315	48/22	.3388185	71/34	.3197794	101/50	.3053541	114/59	.2860529	80/43	.2696215	52/29	.2536053
89/39	.3583254	109/50	.3384565	90/43	.3207740	103/51	.3052670	85/44	.2859662	93/50	.2695129	95/53	.2534477
73/32	.3581729	85/39	.3383533	113/54	.3206846	105/52	.3051860	56/29	.2857900	106/57	.2694310	43/24	.2532573
57/25	.3579349	61/28	.3381718	46/22	.3203351	107/53	.3051079	83/43	.2856096	119/64	.2693670	120/67	.2531064
98/43	.3577576	98/45	.3380136	117/56	.3199977	109/54	.3050327	110/57	.2855178	39/21	.2688453	77/43	.2530222
41/18	.3575114	37/17	.3377528	50/24	.3187588	111/55	.3049603	54/28	.2852358	115/62	.2683061	111/62	.2529313
107/47	.3572859	87/40	.3374593	119/57	.3196721	113/56	.3048904	79/41	.2848432	102/55	.2682375	34/19	.2527253
66/29	.3571459	50/23	.3372422	48/23	.3195134	115/57	.3048229	52/27	.2846395	89/48	.2681488	93/52	.2524796
91/40	.3569814	113/52	.3370751	73/35	.3192549	117/58	.3047577	77/40	.2844307	76/41	.2680297	59/33	.2523381
116/51	.3568878	63/29	.3369525	98/47	.3191282	119/59	.3046950	102/53	.2843243	63/34	.2678616	84/47	.2521814
50/22	.3565473	76/35	.3367456	102/49	.3184041	2/1	.3010300	50/26	.2839967	113/61	.2677486	109/61	.2520967
109/48	.3561853	89/41	.3366061	77/37	.3182890	119/60	.2973957	98/51	.2836559	50/27	.2676062	50/28	.2518120
84/37	.3560776	102/47	.3365023	52/25	.3180633	117/59	.2973337	73/38	.2835393	87/47	.2674214	116/65	.2515446
59/26	.3558787	115/53	.3364219	79/38	.3178435	115/58	.2972698	48/25	.2833012	37/20	.2671717	91/51	.2514712
93/41	.3556990	39/18	.3357921	106/51	.3177357	113/57	.2972035	119/62	.2831553	98/53	.2669502	66/37	.2513422
68/30	.3553876	119/55	.3351843	54/26	.3174204	111/56	.2971350	71/37	.2830566	61/33	.2668159	107/60	.2512325
111/49	.3551269	106/49	.3351098	110/53	.3171168	109/55	.2970638	94/49	.2829318	85/46	.2666611	41/23	.2510561
77/34	.3550118	93/43	.3350144	83/40	.3170181	107/54	.2969900	117/61	.2828559	109/59	.2665745	98/55	.2508634
120/53	.3549053	80/37	.3348883	56/27	.3168242	105/53	.2969134	46/24	.2825466	48/26	.2662679	57/32	.2507249
43/19	.3547149	67/31	.3347131	85/41	.3166350	103/52	.2968339	113/59	.2822264	107/58	.2659558	73/41	.2505390
95/42	.3544743	54/25	.3344538	114/55	.3165422	101/51	.2967512	90/47	.2821446	59/32	.2657020	89/50	.2504200
52/23	.3542755	95/44	.3342709	58/28	.3162700	99/50	.2966652	67/35	.2820068	94/51	.2655577	105/59	.2503373
113/50	.3541084	41/19	.3340303	118/57	.3160071	97/49	.2965756	111/58	.2818950	35/19	.2653144	32/18	.2498775
61/27	.3539660	69/32	.3336991	89/43	.3159215	95/48	.2964824	44/23	.2817249	116/63	.2651175	119/67	.2494722
70/31	.3537363	110/51	.3338225	60/29	.3157533	93/47	.2963850	109/57	.2815516	81/44	.2650323	103/58	.2494092
79/35	.3535591	97/45	.3335592	91/44	.3155887	91/46	.2962836	65/34	.2814345	46/25	.2648178	87/49	.2493232
88/39	.3534181	56/26	.3332147	62/30	.3152704	89/45	.2961775	86/45	.2812860	103/56	.2646492	71/40	.2491983
97/43	.3533032	99/46	.3328774	95/46	.3149658	87/44	.2960666	107/56	.2811958	68/37	.2643062	55/31	.2490010
106/47	.3532080	71/33	.3327444	64/31	.3148183	85/43	.2959504	42/22	.2808266	79/43	.2641586	94/53	.2488520

GEAR LOGS .2486261 TO .1538149

Ratio	Log	Ratio	Log	Ratio	Log	Ratio	Log	Ratio	Log	Ratio	Log	Ratio	Log
39/22	.2486261	113/66	.2335345	53/32	.2191259	69/43	.2053806	109/70	.1923285	65/43	.1794449	85/58	.1659909
101/57	.2484465	101/59	.2334694	101/61	.2189916	77/48	.2052495	28/18	.1918855	68/45	.1792964	63/43	.1658720
62/35	.2483237	77/45	.2332782	48/29	.2188432	85/53	.2051430	115/74	.1914661	71/47	.1791604	104/71	.1657750
85/48	.2481777	65/38	.2331298	91/55	.2186787	93/58	.2050549	101/65	.1914080	74/49	.1790356	41/28	.1656259
108/61	.2480940	118/69	.2330329	43/26	.2184952	101/63	.2049809	87/56	.1913313	77/51	.1789205	101/69	.1654723
46/26	.2477845	53/31	.2329142	81/49	.2182889	109/68	.2049176	73/47	.1912250	80/53	.1788141	60/41	.1653674
99/56	.2474472	94/55	.2327652	119/72	.2182145	117/73	.2048680	59/38	.1910684	83/55	.1787154	79/54	.1652333
76/43	.2473451	41/24	.2325727	38/23	.2180558	32/20	.2041200	104/67	.1909585	86/57	.1786236	98/67	.1651513
53/30	.2471536	111/65	.2324096	109/66	.2178826	115/72	.2033653	45/29	.1908145	89/59	.1785380	117/80	.1650957
83/47	.2469802	70/41	.2323141	71/43	.2177898	107/67	.2033090	76/49	.1906175	92/61	.1784580	38/26	.1648103
113/64	.2468984	29/17	.2319491	104/63	.2176928	99/62	.2032435	107/69	.1905347	95/63	.1783831	111/76	.1645094
30/17	.2466724	104/61	.2317035	33/20	.2174839	91/57	.2031665	31/20	.1903317	101/67	.1782466	92/63	.1644473
97/55	.2464090	75/44	.2316086	94/57	.2172530	83/52	.2030148	110/71	.1901344	104/69	.1781842	73/50	.1643529
67/38	.2462912	46/27	.2313940	61/37	.2171281	75/47	.2029634	79/51	.1900569	107/71	.1781255	54/37	.1641921
104/59	.2461813	109/64	.2312465	89/54	.2169962	67/42	.2028255	48/31	.1898795	110/73	.1780698	89/61	.1640602
37/21	.2459824	63/37	.2311388	117/71	.2169274	59/37	.2026503	113/73	.1897555	113/75	.1780171	35/24	.1638568
118/67	.2458072	80/47	.2309921	28/17	.2167091	110/69	.2025436	65/42	.1896641	116/77	.1779673	86/59	.1636465
81/46	.2457272	97/57	.2308968	107/65	.2164704	51/32	.2024202	82/53	.1895389	119/79	.1779199	51/35	.1635022
44/25	.2455127	114/67	.2308301	79/48	.2163859	94/59	.2022759	99/64	.1894552	24/16	.1760912	118/81	.1633970
95/54	.2453298	34/20	.2304489	51/31	.2162085	43/27	.2021047	116/75	.1893967	118/79	.1742549	67/46	.1633170
51/29	.2451722	107/63	.2300433	74/45	.2160192	78/49	.2018985	34/22	.1890562	115/77	.1742071	83/57	.1632032
109/62	.2450348	90/53	.2299666	97/59	.2159197	113/71	.2018199	105/68	.1886804	112/75	.1741567	99/68	.1631263
58/33	.2449141	73/43	.2298545	120/73	.2158583	35/22	.2016453	88/57	.1886078	109/73	.1741036	115/79	.1630707
65/37	.2447117	56/33	.2296741	46/28	.2155998	97/61	.2014419	71/46	.1885005	106/71	.1740476	32/22	.1627273
72/41	.2445486	95/56	.2295356	110/67	.2153179	62/39	.2013271	54/35	.1883258	103/69	.1739881	109/75	.1623652
79/45	.2444146	39/23	.2293368	87/53	.2152434	89/56	.2012020	91/59	.1881894	100/67	.1739252	93/64	.1623029
86/49	.2443024	100/59	.2291480	64/39	.2151154	116/73	.2011351	37/24	.1879905	97/65	.1738583	77/53	.1622148
93/53	.2442070	61/36	.2290273	105/64	.2150093	27/17	.2009149	94/61	.1877981	94/63	.1737874	61/42	.1620805
100/57	.2441251	83/49	.2288820	41/25	.2148439	100/63	.2006595	57/37	.1876722	91/61	.1737116	106/73	.1619830
107/61	.2440540	105/62	.2287976	100/61	.2146702	73/46	.2005651	77/50	.1875207	88/59	.1736307	45/31	.1618508
114/65	.2439915	44/26	.2284793	59/36	.2145495	119/75	.2004862	97/63	.1874312	85/57	.1735440	119/82	.1617331
28/16	.2430380	115/68	.2281889	77/47	.2143928	92/58	.2003598	117/76	.1873721	82/55	.1734512	74/51	.1616615
117/67	.2421109	93/55	.2281200	95/58	.2142956	111/70	.2002250	40/26	.1870867	79/53	.1733712	103/71	.1615789
110/63	.2420522	71/42	.2280090	113/69	.2142293	65/41	.2001295	103/67	.1867624	76/51	.1732434	29/20	.1613680
103/59	.2419852	120/71	.2279229	36/22	.2138798	84/53	.2000034	83/54	.1866843	73/49	.1731268	100/69	.1611509
96/55	.2419085	49/29	.2277981	103/63	.2134967	103/65	.1999238	63/41	.1865566	70/47	.1730001	71/49	.1610622
89/51	.2418198	76/45	.2276011	67/41	.2132909	38/24	.1995724	106/69	.1864568	67/45	.1728623	113/78	.1609838
82/47	.2417160	103/61	.2275074	116/71	.2131997	106/67	.1992311	43/28	.1863105	64/43	.1727115	42/29	.1608513
75/43	.2415928	27/16	.2272438	49/30	.2130748	87/55	.1991566	109/71	.1861682	61/41	.1725459	97/67	.1606969
68/39	.2414443	113/67	.2270036	80/49	.2128939	68/43	.1990404	66/43	.1860754	119/80	.1724570	55/38	.1605791
61/35	.2412618	86/51	.2269283	111/68	.2128141	117/74	.1989540	89/58	.1859620	58/39	.1723634	68/47	.1604110
115/66	.2411539	59/35	.2267840	31/18	.2126081	49/31	.1988344	112/73	.1858951	113/76	.1722648	81/56	.1602970
54/31	.2410321	91/54	.2266476	106/65	.2123925	79/50	.1986571	46/30	.1856365	55/37	.1721610	94/65	.1602145
101/58	.2408934	32/19	.2263964	75/46	.2123035	109/69	.1985774	95/62	.1853319	107/72	.1720513	107/74	.1601521
47/27	.2407341	101/60	.2261701	119/73	.2122241	30/19	.1983677	72/47	.1852346	52/35	.1719353	120/83	.1601031
87/50	.2405493	69/41	.2260652	44/27	.2120889	101/64	.1981414	49/32	.1850461	101/68	.1718125	26/18	.1597008
40/23	.2403322	106/63	.2259654	101/62	.2119297	71/45	.1980458	75/49	.1848652	49/33	.1716822	114/79	.1592778
113/65	.2401650	37/22	.2257790	57/35	.2118069	112/71	.1979597	101/66	.1847775	95/64	.1715436	101/70	.1592234
73/42	.2400736	116/69	.2256089	70/43	.2116295	41/26	.1978106	26/17	.1845244	46/31	.1713961	88/61	.1591529
106/61	.2399761	79/47	.2255292	96/59	.2114192	93/59	.1976309	118/77	.1843913	89/60	.1712387	75/52	.1590580
33/19	.2397603	42/25	.2253093	109/67	.2113517	52/33	.1974894	107/70	.1842858	43/29	.1710705	62/43	.1589232
92/53	.2395119	89/53	.2251141	26/16	.2108534	115/73	.1973749	81/53	.1842091	83/56	.1708901	111/77	.1588323
59/34	.2393731	47/28	.2249399	112/69	.2103689	63/40	.1972805	55/36	.1840602	40/27	.1706962	49/34	.1587172
85/49	.2392228	99/59	.2247832	99/61	.2103054	74/47	.1971338	84/55	.1839166	117/79	.1705586	85/59	.1585669
111/64	.2391430	52/31	.2246416	86/53	.2102226	85/54	.1970151	113/74	.1838467	77/52	.1704974	36/25	.1583625
52/30	.2388820	109/65	.2245131	73/45	.2101104	96/61	.1969414	29/19	.1836444	114/77	.1704142	95/66	.1581797
97/56	.2385837	57/34	.2243960	60/37	.2099496	107/68	.1968749	119/78	.1834524	37/25	.1702617	59/41	.1580681
71/41	.2384744	119/71	.2242887	107/66	.2098399	118/75	.1968207	90/59	.1833905	108/73	.1701036	82/57	.1579390
116/67	.2383832	62/37	.2241900	47/29	.2096999	33/21	.1962947	61/40	.1832698	71/48	.1700171	105/73	.1578664
45/26	.2382492	67/40	.2240148	81/50	.2095150	113/72	.1957459	93/61	.1831531	105/71	.1699310	23/16	.1576078
109/63	.2380860	72/43	.2238640	115/71	.2094395	91/58	.1956134	32/21	.1829307	34/23	.1697511	102/71	.1573419
64/37	.2379783	77/46	.2237329	34/21	.2092596	102/65	.1956868	67/44	.1826221	99/67	.1695604	79/55	.1572644
83/48	.2378369	82/49	.2236176	89/55	.2090273	69/44	.1953964	102/67	.1825254	65/44	.1694607	56/39	.1571234
102/59	.2377482	87/52	.2235160	55/34	.2088838	58/37	.1952263	35/23	.1823402	31/21	.1691424	89/62	.1569983
38/22	.2373609	92/55	.2234251	76/47	.2087157	105/67	.1951145	108/71	.1821655	90/61	.1689127	33/23	.1567861
107/62	.2369921	97/58	.2233437	97/60	.2086204	47/30	.1949766	73/48	.1820817	59/40	.1687920	109/76	.1566129
88/51	.2369125	102/61	.2232704	118/73	.2085591	83/53	.1948022	111/73	.1820001	87/59	.1686673	76/53	.1565377
69/40	.2367891	107/64	.2232038	42/26	.2082759	119/76	.1947334	38/25	.1818436	115/78	.1686032	119/83	.1564689
119/69	.2366979	112/67	.2231432	113/70	.2079804	36/23	.1945747	117/77	.1816952	28/19	.1684044	43/30	.1563472
50/29	.2365720	117/70	.2230879	92/57	.2079129	97/62	.1943800	79/52	.1816238	109/74	.1681948	96/67	.1561964
81/47	.2363871	30/18	.2218487	50/31	.2076083	61/39	.1942652	120/79	.1815541	81/55	.1681223	53/37	.1560742
112/65	.2363046	118/71	.2206237	79/49	.2074310	86/55	.1941358	41/27	.1814201	53/36	.1679734	116/81	.1559730
31/18	.2360892	113/68	.2205695	108/67	.2073490	111/71	.1940647	85/56	.1812309	78/53	.1678187	63/44	.1558878
105/61	.2358595	108/65	.2205104	29/18	.2071255	25/16	.1938200	44/29	.1810547	103/70	.1677392	73/51	.1557527
74/43	.2357632	103/62	.2204455	95/59	.2068716	114/73	.1935820	91/60	.1808901	25/17	.1674911	93/65	.1555694
117/68	.2356768	98/59	.2203741	66/41	.2067600	89/57	.1935151	47/31	.1807362	97/66	.1672278	103/72	.1555047
43/25	.2355285	93/56	.2202949	103/64	.2066572	64/41	.1933961	97/64	.1805917	72/49	.1671364	113/79	.1554513
98/57	.2353512	88/53	.2202068	37/23	.2064739	103/66	.1932933	50/33	.1804561	119/81	.1670620	30/21	.1549020
55/32	.2352127	83/50	.2201081	119/74	.2063153	39/25	.1931246	103/68	.1803283	47/32	.1669479	117/82	.1543718
67/39	.2350102	78/47	.2199967	82/51	.2062437	92/59	.1929358	53/35	.1802079	116/79	.1668309	107/75	.1543225
79/46	.2348693	73/44	.2198702	45/28	.2060545	53/34	.1927970	109/72	.1800940	69/47	.1667512	97/68	.1542628
91/53	.2347665	68/41	.2197250	98/61	.2058963	120/77	.1926905	56/37	.1799863	91/62	.1666497	87/61	.1541895
103/60	.2346859	63/38	.2195569	53/33	.2057620	67/43	.1926063	115/76	.1798842	113/77	.1665877	77/54	.1540969
115/67	.2346230	58/35	.2193600	114/71	.2056466	81/52	.1924817	59/39	.1797874	44/30	.1663314	67/47	.1539769
36/21	.2340833	111/67	.2192482	61/38	.2055462	95/61	.1923938	62/41	.1796078	107/73	.1660609	57/40	.1538149

Ratio	Log	Ratio	Log	Ratio	Log	Ratio	Log	Ratio	Log	Ratio	Log	Ratio	Log
104/73	.1537104	97/70	.1416737	112/83	.1301399	71/54	.1188645	73/57	.1074480	96/77	.0957805	95/78	.0856290
47/33	.1535840	115/83	.1416197	85/63	.1300784	117/89	.1187957	105/82	.1073754	91/73	.0957185	28/23	.0854302
84/59	.1534273	36/26	.1413292	58/43	.1299595	46/35	.1186898	32/25	.1072100	86/69	.0956494	101/83	.0852433
37/26	.1532284	119/86	.1410485	89/66	.1298461	113/86	.1185799	119/93	.1070641	81/65	.0955716	118/97	.0851103
101/71	.1530631	101/73	.1409985	120/89	.1297912	67/51	.1185046	87/68	.1070104	76/61	.0954838	45/37	.0850108
64/45	.1529675	83/60	.1409268	31/23	.1296339	88/67	.1184079	55/43	.1068942	71/57	.0953834	107/88	.0849011
91/64	.1528614	65/47	.1408155	97/72	.1294392	109/83	.1183484	78/61	.1067648	66/53	.0952680	62/51	.0848215
118/83	.1528039	112/81	.1407330	66/49	.1293478	21/16	.1180993	101/79	.1066943	61/49	.0951337	79/65	.0847137
27/19	.1526102	47/34	.1406190	101/75	.1292601	101/77	.1178307	23/18	.1064553	117/94	.0950578	96/79	.0846441
98/69	.1523770	76/55	.1404509	35/26	.1290947	59/45	.1176395	106/83	.1062278	56/45	.0949755	113/93	.0845855
71/50	.1522883	105/76	.1403757	109/81	.1289415	97/74	.1175400	83/65	.1061647	107/86	.0948853	34/28	.0843209
115/81	.1522128	29/21	.1401787	74/55	.1288690	38/29	.1173856	60/47	.1060533	51/41	.0947863	108/89	.0840338
44/31	.1520916	98/71	.1399677	113/84	.1287991	93/71	.1172246	97/76	.1059581	97/78	.0946771	91/75	.0839801
105/74	.1519576	69/50	.1398791	39/29	.1286666	55/42	.1171124	37/29	.1058037	46/37	.0945561	74/61	.0839019
61/43	.1518613	109/79	.1397994	82/61	.1284841	105/80	.1170993	88/69	.1056336	87/70	.0944213	57/47	.0837770
78/55	.1517319	40/29	.1396620	43/32	.1283185	72/55	.1169698	51/40	.1055102	41/33	.0942700	97/80	.0836817
95/67	.1516488	91/66	.1394975	90/67	.1281677	89/68	.1168811	116/91	.1054166	118/95	.0941584	40/33	.0835461
112/79	.1515909	51/37	.1393685	47/35	.1280299	106/81	.1168209	65/51	.1053432	77/62	.0940990	103/85	.0834183
34/24	.1512677	113/82	.1392645	98/73	.1279032	34/26	.1165056	79/62	.1052354	113/91	.0940370	63/52	.0833372
109/77	.1509358	62/45	.1391792	51/38	.1277866	115/88	.1162151	93/73	.1051600	36/29	.0939045	86/71	.0832402
92/65	.1508744	73/53	.1390470	106/79	.1276788	98/75	.1161648	107/84	.1051045	103/83	.0937591	109/90	.0831840
75/53	.1507854	84/61	.1389495	55/41	.1275788	81/62	.1160933	28/22	.1047353	67/54	.0936810	23/19	.0829742
58/41	.1506441	95/69	.1388745	114/85	.1274860	64/49	.1159839	117/92	.1043979	98/79	.0935990	98/81	.0827411
99/70	.1505372	106/77	.1388142	59/44	.1273993	111/85	.1159041	89/70	.1042920	31/25	.0934217	75/62	.0826696
41/29	.1503859	117/85	.1387668	63/47	.1272426	47/36	.1157954	75/59	.1042083	119/96	.0932758	81/67	.0824102
106/75	.1502446	22/16	.1383027	67/50	.1271048	77/59	.1156387	61/48	.1040886	88/71	.0932244	110/91	.0823513
65/46	.1501556	114/83	.1378268	71/53	.1269824	107/82	.1155699	108/85	.1040049	57/46	.0931171	29/24	.0821868
89/63	.1500495	103/75	.1377759	75/56	.1268733	30/23	.1153935	47/37	.1038962	83/67	.0930033	93/77	.0819922
113/80	.1499884	92/67	.1377130	79/59	.1267751	103/79	.1152101	80/63	.1037495	109/88	.0929438	64/53	.0819041
24/17	.1497623	81/59	.1376330	83/62	.1266864	73/56	.1151349	113/89	.1036884	26/21	.0927540	99/82	.0818213
103/73	.1495143	70/51	.1375278	87/65	.1266059	116/89	.1150680	33/26	.1035406	99/80	.0925452	35/29	.0816700
79/56	.1494391	59/43	.1373835	91/68	.1265325	43/33	.1149546	118/93	.1033991	73/59	.0924709	76/63	.0814731
55/39	.1492981	107/78	.1372892	95/71	.1264653	99/76	.1148216	85/67	.1033441	120/97	.0924095	117/97	.0814140
86/61	.1491687	48/35	.1371732	99/74	.1264035	56/43	.1147195	52/41	.1032194	47/38	.0923143	41/34	.0813050
117/83	.1491076	85/62	.1370272	103/77	.1263465	82/63	.1144734	90/71	.1029842	115/93	.0922149	88/73	.0811598
31/22	.1489390	37/27	.1368379	107/80	.1262938	95/73	.1144007	109/86	.1029280	68/55	.0921462	47/39	.0810333
100/71	.1487417	100/73	.1366771	111/83	.1262449	108/83	.1143457	38/30	.1026623	89/72	.0920575	100/83	.0809219
69/49	.1486530	63/46	.1365827	115/86	.1261993	26/20	.1139433	119/94	.1024191	110/89	.0920027	53/44	.0808232
107/76	.1485702	89/65	.1364766	119/89	.1261570	113/87	.1135591	100/79	.1023729	21/17	.0917704	59/49	.0806559
38/27	.1484198	115/84	.1364185	24/18	.1249387	100/77	.1135093	81/64	.1023050	58/47	.0913301	65/54	.0805196
83/59	.1482261	26/19	.1362197	117/88	.1237030	87/67	.1134445	62/49	.1021956	95/77	.0912329	71/59	.0804063
45/32	.1480625	119/87	.1360277	113/85	.1236595	74/57	.1133568	105/83	.1021112	37/30	.0910804	77/64	.0803107
97/69	.1479226	93/68	.1359740	109/82	.1236126	61/47	.1132319	43/34	.1019896	90/73	.0909196	83/69	.0802290
52/37	.1478016	67/49	.1358787	105/79	.1235622	109/84	.1131472	110/87	.1018734	53/43	.0908074	89/74	.0801583
111/79	.1476959	108/79	.1357967	101/76	.1235078	48/37	.1130405	91/72	.1017089	69/56	.0906611	95/79	.0800965
59/42	.1476027	41/30	.1356626	97/73	.1234488	83/64	.1128981	115/91	.1016564	85/69	.0905698	107/89	.0799938
66/47	.1474460	97/71	.1355134	93/70	.1233849	35/27	.1127042	24/19	.1014576	101/82	.0905075	113/94	.0799505
73/52	.1473196	56/41	.1354041	89/67	.1233152	92/71	.1125295	101/80	.1012314	117/95	.0904621	119/99	.0799118
80/57	.1472151	71/52	.1352550	85/64	.1232389	57/44	.1124222	77/61	.1011609	32/26	.0901766	24/20	.0791813
87/62	.1471276	86/63	.1351580	81/61	.1231552	79/61	.1122973	53/42	.1010266	107/87	.0898645	115/96	.0784266
94/67	.1470531	101/74	.1350897	77/58	.1230627	101/78	.1122268	82/65	.1009005	91/74	.0898097	109/91	.0783851
101/72	.1469889	116/85	.1350391	73/55	.1229602	22/17	.1119738	111/88	.1008403	75/61	.0897315	103/86	.0783387
108/77	.1469331	30/22	.1346986	69/52	.1228458	119/92	.1117592	29/23	.1006702	59/48	.0896108	97/81	.0782867
115/82	.1468869	109/80	.1343365	65/49	.1227173	97/75	.1117104	92/73	.1004649	102/83	.0895221	91/76	.0782278
28/20	.1461280	94/69	.1342788	61/46	.1225720	75/58	.1116333	63/50	.1003705	43/35	.0894005	85/71	.0781606
116/83	.1453899	79/58	.1341991	118/89	.1224920	53/41	.1114920	97/77	.1002810	113/92	.0892906	79/66	.0780832
109/78	.1453319	64/47	.1340821	57/43	.1224064	84/65	.1113659	34/27	.1001151	70/57	.0892231	73/61	.0779931
102/73	.1452773	113/83	.1340003	110/83	.1223146	115/89	.1113078	73/58	.0998949	97/79	.0891446	67/56	.0778868
88/63	.1451422	49/36	.1338936	53/40	.1222159	31/24	.1111505	112/89	.0998280	27/22	.0889411	61/51	.0777596
81/58	.1450570	83/61	.1337483	102/77	.1221095	102/79	.1109731	39/31	.0997029	119/97	.0887753	116/97	.0776863
74/53	.1449758	117/86	.1336872	49/37	.1219944	71/55	.1108956	83/66	.0995342	65/53	.0886375	55/46	.0776049
67/49	.1448787	34/25	.1335389	94/71	.1218696	111/86	.1108245	44/35	.0993847	103/84	.0885579	104/87	.0775140
60/43	.1446828	106/78	.1332113	45/34	.1217336	40/31	.1106983	93/74	.0992512	38/31	.0884219	49/41	.0774122
53/38	.1444923	72/53	.1330566	86/65	.1215851	89/69	.1105409	49/39	.0991315	87/71	.0882610	92/77	.0772971
99/71	.1443669	91/67	.1329666	41/31	.1214222	49/38	.1104125	103/82	.0990233	49/40	.0881361	43/36	.0771660
46/33	.1442439	110/81	.1329077	119/90	.1213045	107/83	.1103057	54/43	.0989253	109/89	.0880365	80/67	.0770152
85/61	.1440891	38/28	.1326256	78/59	.1212426	58/45	.1102155	113/90	.0988359	60/49	.0879552	117/98	.0769598
39/28	.1439066	118/87	.1323627	115/87	.1211785	67/52	.1100705	59/47	.0987541	82/67	.0878391	37/31	.0768400
110/79	.1437656	99/73	.1323123	37/28	.1210437	76/59	.1099616	64/51	.0986098	71/58	.0878303	105/88	.0767066
71/51	.1436881	80/59	.1322380	107/81	.1208988	85/66	.1098750	69/55	.0984864	93/76	.0876693	68/57	.0766340
103/74	.1436055	61/45	.1321173	70/53	.1208221	94/73	.1098050	74/59	.0983797	104/85	.0876144	99/83	.0765571
32/23	.1434222	103/76	.1320236	103/78	.1207426	103/80	.1097472	79/63	.0982866	115/94	.0875699	31/26	.0763884
89/64	.1432100	42/31	.1318876	33/25	.1205739	112/87	.1096987	84/67	.0982045	22/18	.0871505	118/99	.0762468
57/41	.1430910	107/79	.1317567	95/72	.1203911	27/21	.1091445	89/71	.0981317	116/95	.0867344	87/73	.0761964
82/59	.1429619	65/48	.1316722	62/47	.1202938	113/88	.1085957	94/75	.0980666	105/86	.0866908	56/47	.0760901
107/77	.1428931	88/65	.1315693	91/69	.1201923	104/81	.1085483	99/79	.0980081	94/77	.0866372	81/68	.0759761
25/18	.1426675	111/82	.1315091	120/91	.1201398	95/74	.1084919	104/83	.0979552	83/68	.0865692	106/89	.0759159
118/85	.1424632	23/17	.1312789	29/22	.1199753	86/67	.1084237	109/87	.0979072	72/59	.0864805	25/21	.0757207
93/67	.1424081	119/88	.1310643	112/85	.1197991	68/53	.1082330	114/91	.0978635	61/50	.0863598	119/100	.0755470
68/49	.1423128	96/71	.1310129	83/63	.1197376	59/46	.1080942	119/95	.0978234	111/91	.0862816	94/79	.0755008
111/80	.1422330	73/54	.1309291	54/41	.1196099	109/85	.1080076	20/16	.0969100	50/41	.0861861	69/58	.0754211
43/31	.1421068	50/37	.1307683	79/60	.1194758	50/39	.1079054	116/93	.0959751	89/73	.0860671	113/95	.0753548
104/75	.1419720	77/57	.1306158	104/79	.1194062	91/71	.1077831	111/89	.0959330	39/32	.0859146	44/37	.0752510
61/44	.1418771	104/77	.1305426	25/19	.1191864	41/32	.1076339	106/85	.0958870	106/87	.0857866	107/90	.0751413
79/57	.1417522	27/20	.1303338	96/73	.1189483	114/89	.1075149	101/81	.0958364	67/55	.0857121	63/53	.0750646

GEAR LOGS .0749648 TO .0036342

Ratio	Log	Ratio	Log	Ratio	Log	Ratio	Log	Ratio	Log	Ratio	Log	Ratio	Log
82/69	.0749648	94/81	.0646429	60/53	.0538754	43/39	.0424079	72/67	.0312577	91/87	.0195221	52/51	.0084331
101/85	.0749025	29/25	.0644580	103/91	.0537958	97/88	.0422890	101/94	.0311935	23/22	.0193893	53/52	.0082726
19/16	.0746336	109/94	.0642986	112/99	.0535828	54/49	.0421977	29/27	.0310342	93/89	.0190929	54/53	.0081179
108/91	.0743824	80/69	.0642409	69/61	.0535193	65/59	.0420614	102/95	.0308766	70/67	.0190232	55/54	.0079689
89/75	.0743287	51/44	.0641175	95/84	.0534443	76/69	.0419645	73/68	.0308140	47/45	.0188854	56/55	.0078253
70/59	.0742460	73/63	.0639824	26/23	.0532455	87/79	.0418922	44/41	.0306688	71/68	.0187493	57/56	.0076869
51/43	.0741017	95/82	.0639097	113/100	.0530784	98/89	.0418361	103/96	.0305660	95/91	.0186822	58/57	.0075531
83/70	.0739801	22/19	.0636691	87/77	.0530286	109/99	.0417913	59/55	.0304893	24/23	.0184834	59/58	.0074240
115/97	.0739262	103/89	.0634472	61/54	.0529360	22/20	.0413926	74/69	.0303826	97/93	.0182888	60/59	.0072993
32/27	.0737862	81/70	.0633818	96/85	.0528523	100/91	.0409586	89/83	.0303119	73/70	.0182249	61/60	.0071785
109/92	.0736387	59/51	.0632181	33/31	.0527063	89/81	.0409050	104/97	.0302616	49/47	.0180982	62/61	.0070619
77/65	.0735773	96/83	.0631931	79/70	.0525291	78/71	.0408363	30/28	.0299632	74/71	.0179734	63/62	.0069488
45/38	.0734289	37/32	.0630517	44/39	.0523881	67/61	.0407450	106/99	.0296707	99/95	.0179116	64/63	.0068395
103/87	.0733179	89/77	.0628993	97/86	.0522732	56/51	.0406178	91/85	.0296225	25/24	.0177288	65/64	.0067334
58/49	.0732319	52/45	.0627908	53/47	.0521780	101/92	.0405336	61/57	.0294549	101/97	.0175497	66/65	.0066305
71/60	.0731070	67/58	.0626468	62/55	.0520290	45/41	.0404286	107/100	.0293838	76/73	.0174907	67/66	.0065309
84/71	.0730210	82/71	.0625556	71/63	.0519178	79/72	.0402946	46/43	.0292893	51/49	.0173741	68/67	.0064341
97/82	.0729578	97/84	.0624924	80/71	.0518317	34/31	.0401172	77/72	.0291582	77/74	.0172590	69/68	.0063402
110/93	.0729098	112/97	.0624463	89/79	.0517629	91/83	.0399633	31/29	.0289637	103/99	.0172020	70/69	.0062489
26/22	.0725506	30/26	.0621479	98/87	.0517068	57/52	.0398716	78/73	.0287717	26/25	.0170333	71/70	.0061603
111/94	.0721951	113/98	.0618523	107/95	.0516602	80/73	.0397671	47/44	.0286452	79/76	.0168135	72/71	.0060742
98/83	.0721480	98/85	.0618072	18/16	.0511525	23/21	.0395085	63/59	.0284885	53/51	.0167057	73/72	.0059904
85/72	.0720864	83/72	.0617456	109/97	.0506548	104/95	.0393597	79/74	.0283954	80/77	.0165993	74/73	.0059088
72/61	.0720027	68/59	.0616569	100/89	.0506100	81/74	.0392533	95/89	.0283336	27/26	.0163905	75/74	.0058296
59/50	.0718820	53/46	.0615181	91/81	.0505564	58/53	.0391521	32/30	.0280287	55/53	.0160868	76/75	.0057523
105/89	.0717993	91/79	.0614143	82/73	.0504910	93/85	.0390640	97/91	.0277303	83/80	.0159881	77/76	.0056771
46/39	.0716932	38/33	.0612697	73/65	.0504094	35/32	.0389180	81/76	.0276714	28/27	.0157942	78/77	.0056039
79/67	.0715523	99/86	.0611367	64/57	.0503051	82/75	.0387526	65/61	.0275836	85/82	.0156050	79/78	.0055325
112/95	.0714944	61/53	.0610539	55/49	.0501666	47/43	.0386294	49/46	.0274383	57/55	.0155122	80/79	.0054629
33/28	.0713559	84/73	.0609564	101/90	.0500789	106/97	.0385342	33/31	.0271522	86/83	.0154204	81/80	.0053950
86/73	.0711756	107/93	.0609009	46/41	.0499739	59/54	.0384582	83/78	.0269835	29/28	.0152400	82/81	.0053289
53/45	.0710634	23/20	.0606978	83/74	.0498464	71/65	.0383449	50/47	.0268721	88/85	.0150638	83/82	.0052642
73/62	.0709312	100/87	.0604807	37/33	.0496878	83/76	.0382645	67/63	.0267343	59/57	.0149771	84/83	.0052012
93/79	.0708558	77/67	.0604159	102/91	.0495588	95/87	.0382043	84/79	.0266522	89/86	.0148915	85/84	.0051396
113/96	.0708072	54/47	.0602959	65/58	.0494854	107/98	.0381577	101/95	.0265978	30/29	.0147233	86/85	.0050796
20/17	.0705811	85/74	.0601872	93/83	.0494048	24/22	.0377886	17/16	.0263289	91/88	.0145587	87/86	.0050208
107/91	.0703424	31/27	.0599979	28/25	.0492180	109/100	.0374265	103/97	.0260655	61/59	.0144768	88/87	.0049634
87/74	.0702876	101/88	.0598387	103/92	.0490494	97/89	.0373817	86/81	.0260135	92/89	.0143978	89/88	.0049073
67/57	.0701999	70/61	.0597688	75/67	.0489865	85/78	.0373243	69/65	.0259357	31/30	.0142404	90/89	.0048525
114/97	.0701332	109/95	.0597029	47/42	.0488486	73/67	.0372481	52/49	.0258928	94/91	.0140865	91/90	.0047989
47/40	.0700379	39/34	.0595857	66/59	.0486919	61/56	.0371418	87/82	.0257084	63/61	.0140107	92/91	.0047464
74/63	.0698912	86/75	.0594372	85/76	.0486053	49/45	.0369836	35/33	.0255541	95/92	.0139358	93/92	.0046951
101/86	.0698229	47/41	.0593140	104/93	.0485504	86/79	.0368714	88/83	.0254046	32/31	.0137883	94/93	.0046450
27/23	.0696360	102/89	.0592102	19/17	.0483047	37/34	.0367228	53/50	.0253059	97/94	.0136438	95/94	.0045957
115/98	.0694717	55/48	.0591215	105/94	.0480614	99/91	.0365938	71/67	.0251835	65/63	.0135729	96/95	.0045476
88/75	.0694214	63/55	.0589778	86/77	.0479978	62/57	.0365168	89/84	.0251107	98/95	.0135025	97/96	.0044554
95/81	.0692386	71/62	.0588666	67/60	.0479235	87/80	.0364293	18/17	.0248241	33/32	.0133639	98/97	.0044005
61/52	.0692265	79/69	.0587780	48/43	.0477727	25/23	.0362122	91/86	.0245429	100/97	.0132283	99/98	.0044091
34/29	.0690809	87/76	.0587057	77/69	.0476416	88/81	.0359977	73/69	.0244738	67/65	.0131614	100/99	.0043648
109/93	.0689436	95/83	.0586455	106/95	.0475823	63/58	.0359125	55/52	.0243594	101/98	.0130953	101/100	.0043214
75/64	.0688813	103/90	.0585947	97/87	.0472524	101/93	.0358385	92/87	.0242687	34/33	.0139650	102/101	.0042788
116/99	.0688228	24/21	.0579920	39/35	.0469966	38/35	.0357156	37/35	.0241337	103/100	.0128372	103/102	.0042370
41/35	.0687159	113/99	.0574432	88/79	.0468556	89/82	.0355761	93/88	.0240002	69/67	.0127743	104/103	.0041961
89/76	.0685764	105/92	.0574015	49/44	.0467434	51/47	.0354723	56/53	.0239121	35/34	.0125891	105/104	.0041560
48/41	.0684573	97/85	.0573528	108/97	.0466521	64/59	.0353280	75/71	.0238030	36/35	.0122345	106/105	.0041166
103/88	.0683545	89/78	.0572954	59/53	.0465761	77/71	.0352324	94/89	.0237379	73/71	.0120646	107/106	.0040779
55/47	.0682648	81/71	.0572267	69/62	.0464574	90/83	.0351644	19/18	.0234811	37/36	.0118992	108/107	.0040400
117/100	.0681857	73/64	.0571429	79/71	.0463688	103/95	.0351136	96/91	.0232298	75/73	.0117384	109/108	.0040027
62/53	.0681158	65/57	.0570385	89/80	.0463000	26/24	.0347621	77/73	.0231678	38/37	.0115819	110/109	.0039662
69/59	.0679971	57/50	.0569049	99/89	.0462452	105/97	.0344176	58/55	.0230653	77/75	.0114294	111/110	.0039303
76/65	.0679002	106/93	.0568230	109/98	.0462004	92/85	.0343689	97/92	.0229839	39/38	.0112810	112/111	.0038950
83/71	.0678193	49/43	.0567276	20/18	.0457575	79/73	.0343042	39/37	.0228629	79/77	.0111364	113/112	.0038604
90/77	.0677518	90/79	.0566154	111/100	.0453230	66/61	.0342141	98/93	.0227832	40/39	.0109954	114/113	.0037265
97/83	.0676936	41/36	.0564814	101/91	.0452800	53/49	.0340798	59/56	.0226640	81/79	.0108571	115/114	.0037929
104/89	.0676433	74/65	.0563183	91/82	.0452275	93/86	.0339844	79/75	.0225658	41/40	.0107239	116/115	.0037602
111/95	.0675994	107/94	.0562559	81/73	.0451621	40/37	.0338583	99/94	.0225073	83/81	.0105931	117/116	.0037277
21/18	.0669467	33/29	.0561159	71/64	.0450783	107/99	.0337486	20/19	.0222764	42/41	.0104654	118/117	.0036963
113/97	.0663067	91/80	.0559514	61/55	.0449671	67/62	.0336831	101/96	.0220502	85/83	.0103408	119/118	.0036650
106/91	.0662645	58/51	.0558578	51/46	.0448124	94/87	.0336086	81/77	.0219943	43/42	.0102192	120/119	.0036342
99/85	.0662163	83/73	.0557552	92/83	.0447097	27/25	.0334238	61/58	.0219018	87/85	.0101004		
92/79	.0661607	108/95	.0557002	41/37	.0445822	95/88	.0332409	103/98	.0216011	44/43	.0099842		
85/73	.0660960	25/22	.0555173	72/65	.0444191	68/63	.0331684	62/59	.0215397	89/87	.0098707		
78/67	.0660198	92/81	.0553028	103/93	.0443543	41/38	.0330003	83/79	.0214510	45/44	.0097440		
71/61	.0659285	67/59	.0552228	31/28	.0442037	96/89	.0328812	104/99	.0213981	91/89	.0096514		
64/55	.0658173	109/96	.0551553	83/75	.0440168	55/51	.0327925	21/20	.0211892	46/45	.0095453		
57/49	.0656788	42/37	.0550476	52/47	.0439054	69/64	.0326691	85/81	.0209339	93/91	.0094415		
107/92	.0655960	101/89	.0549314	73/66	.0437790	83/77	.0325874	64/61	.0208502	47/46	.0093401		
50/43	.0655015	59/52	.0548487	21/19	.0434657	97/90	.0325292	43/41	.0206846	95/93	.0092407		
93/80	.0653929	76/67	.0547388	95/86	.0432251	28/26	.0321847	65/62	.0205217	48/47	.0091433		
43/37	.0652668	93/82	.0546690	74/67	.0431569	99/92	.0318474	87/83	.0204412	97/95	.0090481		
79/68	.0651182	110/97	.0546210	53/48	.0430347	85/79	.0317918	22/21	.0202034	49/48	.0089549		
115/99	.0650626	34/30	.0543576	85/77	.0429282	71/66	.0317144	89/85	.0199711	99/97	.0088635		
36/31	.0649408	111/98	.0540969	32/29	.0427520	57/53	.0315990	67/64	.0198948	50/49	.0087739		
101/87	.0648021	94/83	.0540498	107/97	.0426121	100/93	.0315171	45/43	.0197440	101/99	.0086862		
65/56	.0647254	77/68	.0539818	75/68	.0425524	43/40	.0314085	68/65	.0195955	51/50	.0086002		

DESIGNING

High Pressure Pumps

DESIGN ABSTRACTS

. . . for controlled volume applications

By Donald H. Jones *Mechanical Engineer, Milton Roy Co., Philadelphia, Pa.*

ANY thorough examination of current trends in process development should include consideration of the steady move toward higher operating pressures in various fields. Certain reactions which are favored at higher pressures are being investigated not only in the laboratory, but are now being expanded into semi and even into full commercial scale. Reactions formerly undertaken only at lower pressures are being developed for use at high pressures because of higher efficiencies and better yields. Equipment manufacturers have felt the impact of this trend in that high-pressure specifications are definitely increasing.

Pump Development: Controlled-volume pumps are reciprocating plunger, positive-displacement type pumps specifically designed to accurately deliver a metered quantity to a point of application. During the past 15 years, this classification of pumps has developed from a mere adaptation of inaccurate forced-feed lubricators to the point where they are now considered precision instruments for the process industries. Basically, these pumps consist of a plunger reciprocating in a specifically designed displacement chamber with check valves on suction and discharge sides.

A properly designed displacement chamber, or liquid end, permits a controlled volume to be delivered for each plunger stroke; a quantity determined by the plunger diameter and plunger stroke length. A typical liquid end for a controlled-volume pump employs double check valves on both suction and discharge side to assure the continuance of accurate pumping should one check be temporarily held off its seat. The checks are so arranged as to automatically discharge any entrained air or gas impairing volumetric efficiency.

Capacity Adjustment: Capacity is adjusted by changing the plunger displacement. Two methods of plunger stroke length adjustment are generally available on motor-driven controlled-volume pumps. Stroke adjustment while the pump is stopped is usually made by adjusting the throw of the connecting rod through turning the crank screw. Frequently, however, it is not possible to stop operation in order to make capacity adjustments. Adjustment while the pump is in operation can be accomplished by using a mechanism capable of varying the relative positions of a fixed connecting rod and a variable drive rod. Capacity regulation can also be made by adjustment of the stroke speed, or frequency of plunger strokes made per minute,

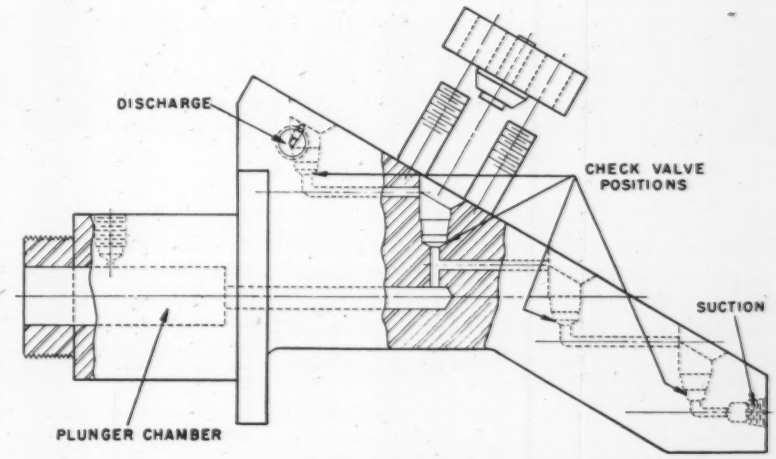


Fig. 1—Typical liquid end for high-pressure controlled-volume pump is machined from a solid forging with passages connecting suction and discharge openings

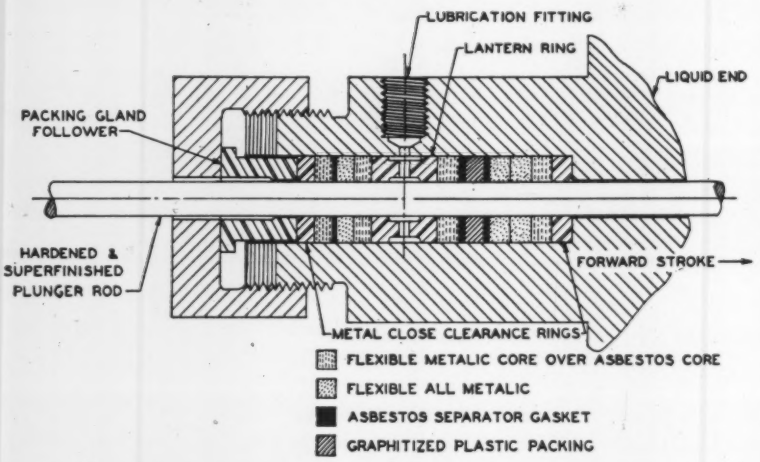


Fig. 2—Plunger stuffing box design employing metallic packing has been the most successful for pressures up to 30,000 psi

while the pump is operating. Various means of speed regulation have been employed, including those permitting automatic regulation by process variables. Continuous operation makes automatic lubrication desirable.

In addition to motor drive, controlled-volume pumps powered by double-acting fluid cylinders are available. Fluid pressures such as plant air pressures can be employed in the cylinder to obtain desired pump discharge pressures. The straight-through stroking action makes this design desirable for future higher pressure developments since the crank mechanism required on the motor-driven types is eliminated. Capacity adjustment is again made by regulation of the plunger stroke length, or by control of the number of strokes per minute.

Stroke length adjustment on fluid powered pumps differs from that on motor driven pumps where adjustment is made around the center of the crank. In the fluid powered pumps adjustment of the stroke length is made by limiting the return stroke of the plunger. The forward position of the plunger is always the same regardless of stroke length, permitting maximum scavenging of the liquid end at all times and reducing the effect of compressibility on capacity delivered. Self-reciprocating fluid-powered, controlled-volume pumps are employed as self-balancing hydrostatic pressure generators, automatically building up the pressure in the system, or chamber to be tested, until the fluid pressure acting on the piston area is balanced by the hydrostatic pressure acting on the plunger area. At this point the hydrostatic pressure is maintained at the desired value. If there is a small leak in the system, the plunger will move slowly forward to take up the leakage and maintain the pressure.

Design of Liquid Ends: As research into high-pressure reactions increased, the manufacturers of controlled volume pumps designed special high-pressure liquid ends in order that the equipment would meet the requirements for service in the range of 10,000 to 30,000 psi. Much of the design of the reciprocating mechanism in the lower pressure pumps is used by enlarging parts, increasing bearing areas, strengthening parts by changing materials of construction, and redesigning members such as the plunger where column action must be considered.

Major changes are in the liquid end, or displacement chamber, where the higher pressures are encountered. A solid forging is required with the passages connecting suction and discharge openings, and between one check valve and another, being machined rather than cast. It is necessary to maintain a similar arrangement of the check valves as on liquid ends for lower pressure units in order to achieve controlled volume pumping. An additional requirement is the necessity of keeping the total internal volume of the liquid end as small as possible because of the compressibility effect on liquids at higher pressures. These factors are all considered in the present design, *Fig.* 1. Liquid ends of this type are machined from forgings of stainless as well as carbon steel.

The major problem facing any designer of high-pressure equipment is the development of methods of sealing. Such sealing involves the use of joints, gaskets, and packing of one form or another. In the high-pressure liquid end described, three types of seals are employed. The liquid end discharge outlet which is connected to the high-pressure system must be sealed. This is readily accomplished by using various tubing adaptors available, so that standard high-pressure tubing is utilized.

Openings over the check valves which permit individual inspection must also be sealed and this is done by using mushroom plugs so machined as to give a tight metal-to-metal seal with the sockets machined in the liquid end body. Such an arrangement has been found satisfactory for pressures to 25,000 psi. For pressures from 25,000 to 30,000 psi, it is necessary to incorporate a soft metal gasket between the mushroom plug and the socket, a successful method on which the limiting pressure has not yet been reached.

The third and most difficult problem involves the sealing of the reciprocating plunger. Many methods were attempted to develop a special stuffingbox design suitable for use with plungers reciprocating at speeds up to 100 strokes per minute on 3 to 4-inch maximum stroke lengths. It was hoped that some form of "unsupported area" packing might be employed but this is not readily adaptable to a reciprocating plunger. The most successful plunger stuffingbox combination found thus far, *Fig.* 2, includes the use of a hardened plunger superfinished to 3 to 5 micro inches, with a special packing arrangement consisting of soft metallic foil packing combined with other packing materials. Such a

combination has proved satisfactory up to a maximum pressure of 30,000 psi.

Compressibility Effects: One of the most interesting effects of high pressure is the resulting compressibility of liquids. While investigators have been successful in measuring the compressibility of materials for pressures over 1,000,000 psi, the average engineer has little concept of the magnitude of this effect even in the lower high-pressure range from 10,000 to 30,000 psi. Compressibility is of even greater importance in this range, for the compressibility, of necessity, decreases greatly with increasing pressure; so much that the average compressibility factor of a liquid at atmospheric pressure decreases to about one half of this value when measured at approximately 15,000 psi. Therefore, the importance of compressibility in this range is such as to suggest most careful consideration by the engineer, particularly as this is the range in which most problems are being investigated today.

How this compressibility effects the design of high-pressure pumps was initially described by Schmoyer ("Compressibility of Liquids," MACHINE DESIGN, Aug., 1947, page 134). The graph, *Fig.* 3, clearly illustrates the effect of the ratio, r, on the theoretical volumetric efficiency with increasing pressure for pumps using water; r is the ratio of the total internal volume of the liquid end of a pump to a displacement of its plunger or piston. These curves were obtained from calculations based on

$$e_v = 100 - \beta\ (r - 1)p$$

where e_v is the theoretical volumetric efficiency, β is the compressibility factor (contraction in unit volume per atmosphere of pressure), and p is the operating pressure in atmospheres. The formula itself is derived from the observation that not merely the volume displaced by the plunger, but the total internal volume between operating valve checks must be compressed to the operating pressure. Volume displaced per stroke, therefore, will be reduced by the amount the total internal volume has been compressed.

Theoretical volumetric efficiency or the ratio of the plunger displacement accounting for compressibility to the actual plunger displacement is also affected. For this graph, water is assumed to be at a constant temperature and β, the compressibility factor, is assumed to be an average value, 4.3×10^{-5}. No attempt has been made in this graph to compensate for slippage through the valves so as to show actual volumetric efficiencies rather than theoretical, since the slippage factor will vary depending on the fluid handled, liquid end design, and valve check or valve seat wear.

The graph clearly points out the necessity for consideration of the ratio r in the design of liquid ends for high-pressure pumps; at 13,000 psi with $r = 14$, only half of the plunger displacement could theoretically be discharged. For all calculations made in this graph, the compressibility factors are based on a constant temperature and all compressions are assumed to be isothermal. In actual pumping there is a temperature rise due to the heat of compression. This heat of compression causes the volume of the liquid to expand which in some measure has an opposite effect to the compressibility. Also, with a specific pump having a constant r, the theoretical volumetric efficiency will vary at different rates for different liquids, indicating that the designer must carefully consider the liquid to be pumped and its individual compressibility.

Since controlled-volume pumps have adjustable plunger stroke lengths to permit capacity adjust-

(*Continued on Page* 266)

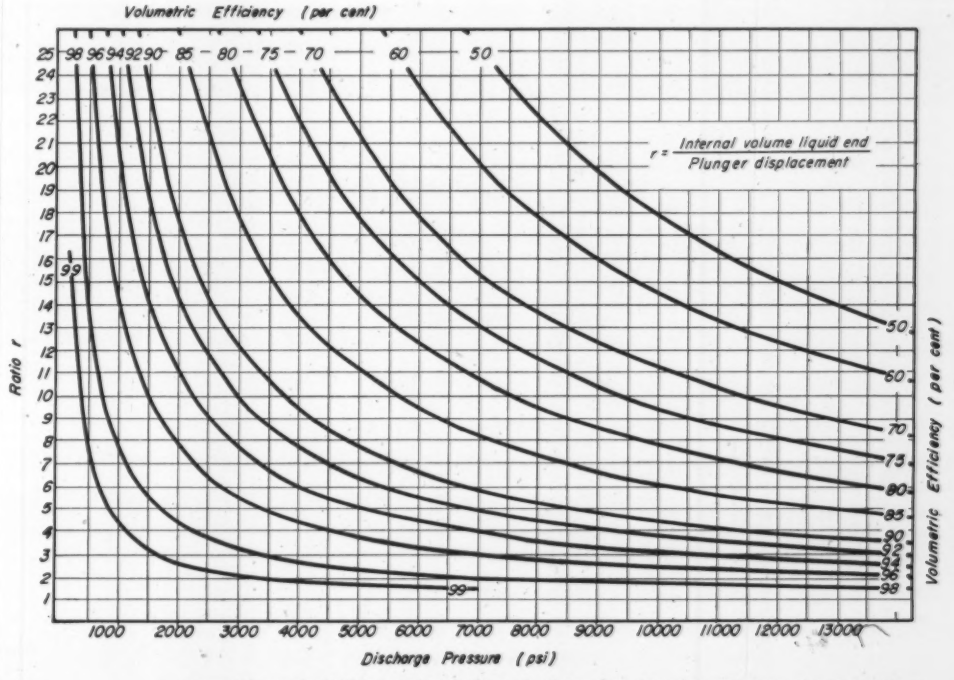


Fig. 3—Graph of theoretical volumetric efficiency indicates effects of ratio r and compressibility for high pressure pumps using water

From "Compressibility of Liquids," R. L. Schmoyer, MACHINE DESIGN, *August* 1947.

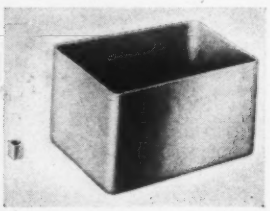
NEW PARTS

CASES AND COVERS 1

. . . available from stock

Hudson Tool and Die Co., 118 *S.* 14*th S., Newark* 7, *N. J.*

Hundreds of stock sizes are available in a variety of shapes and materials.



Size: From $\frac{1}{16}$ by $\frac{1}{16}$ by $1\frac{1}{16}$ in. to 16 by 10 by $7\frac{1}{2}$ in.

Service: Instrument dial and gage boxes; electronic and radar assembly chassis; electric assembly cases and housings; junction and coil boxes.

Design: Square, round or rectangular deep-drawn cases and covers of aluminum, brass, copper or steel.

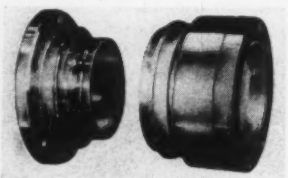
For more data circle MD-1, Page 209

PIPE CONNECTOR 2

. . . easily connected or disconnected

Snap-Tite Inc., Union City, Pa.

Connection can be made or broken by sliding a sleeve on the connector; no tools are needed.



Size: For 8 in. pipe.

Service: Connecting pipe; for liquid, air, gas or vacuum; flow automatically shuts off when connection is broken; eliminates cross-threading when making connections; swivels through 360 deg.

Design: Quick-disconnect connector of forged-steel or bronze; flanged type; valve in body stops flow when male portion is removed; also available without valve; small sizes from ¼-in. also available; other materials can be used for specials.

For more data circle MD-2, Page 209

METAL ADHESIVE 3

. . . bonds without surface preparation

Armstrong Products Co., P.O. Box No. 1, *Warsaw, Ind.*

No priming or special preparation of surfaces to be joined is necessary.

Designation: A-6.

Form: Powder and separate liquid activator.

Size: 3 oz tube, pint, quart, gal and 5 gal pails.

Service: Joining aluminum, steel, copper, tungsten carbide, ceramics and other materials; provides strong, liquid-tight seams; resists oil, aircraft fuels, water and most solvents at temperatures from — 70 to 180 F.

Properties: Results of shear strength tests when joining 24 ST aluminum are:

Shear Strength (psi)	Conditions
3000	at 70 F
2400	at 180 F
2900	at —70 F
3000	after 30 days water immersion
3300	after 7 days in ethylene glycol
3400	after 7 days in oil
3300	after 30 day salt spray

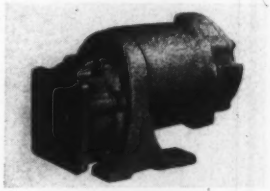
For more data circle MD-3, Page 209

GEARMOTOR 4

. . . is small and light

U. S. Electrical Motors Inc., Box 2058 *Terminal Annex, Los Angeles* 54, *Calif.*

Weighing only 17 lb complete with gears, this motor develops 2 hp.



Designation: Type GA.

Size: 10 in. long, 6 in. high, $5\frac{3}{4}$ in. wide; weighs 17 lb.

Service: Connecting pipe; for liquid, air, gas or vacof 1500 to 5000 rpm; operates on 200 v, 400 cycle, 3-phase ac.

Design: 3-phase ac gear motor; hardened and shaved helical gears; design meets AF Spec 32590; internal splined shaft, 0.906-in. long, has 12-tooth involute form, 30-deg pressure angle, 0.600-in. pitch diam; integral fan for ventilation; four mounting holes spaced $4\frac{1}{4}$ in.

For more data circle MD-4, Page 209

NEW PARTS

SCRAPER RINGS 5

. . . reduce cylinder wear

Gadgets Inc., 3629 N. Dixie Drive, Dayton, O.

By removing dirt, dust and abrasives from piston rods, these scraper rings prevent wear of internal cylinder parts.

Designation: Super-Seal.

Size: ½ to 13 in. ID.

Service: Exceed wear requirements of MIL-5-5049 specification more than 20 times; prolonging life of cylinders by removal of dirt, dust or other abrasive material from piston rod, thereby preventing wear of packings, cylinder walls and other parts.

Design: Split ring with built-in twist to place a sharp edge against the piston rod surface; produced under Army-Navy standard drawing No. AN 6231 in both standard and A series rings.

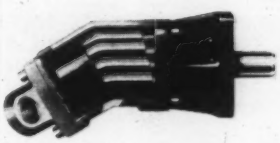
For more data circle MD-5, Page 209

POSITIVE-DISPLACEMENT PUMP 6

. . . requires no lubrication

Eastman Pacific Co., 2320 E. 8th St., Los Angeles 28, Calif.

Pump delivers 7.2 gpm at 433 psi and with aluminum body weighs only 2½ lb.



Designation: Dudley V-9 model 100.

Size: 7.250 in. long, 3.37 in. high, 2.44 in. wide; weight is 5 lb with bronze body, 2½ lb with aluminum body; splined shaft with 1.062 in. extension, or 0.625-in. keyed shaft with 1.250 in. extension; inlet port ½-in. pipe size, outlet port ⅜-in. pipe size.

Service: Pumping water, brine, oil, gasoline or other liquids; operating temperature range from — 60 to 165 F; shaft rotation clockwise, easily reversed if desired; delivers from 2.4 to 7.2 gpm at pressures from 9 to 433 psi at speeds to 3600 rpm; maximum recommended inlet pressure is 200 psi; may be operated at speeds to 10,000 rpm but life will be shortened.

Design: Positive-displacement pump; 9 sleeves extend into each of 2 cylinder blocks whose angular relation causes a telescoping cylinder effect when cylinder blocks are rotated; body of aluminum or bronze; designed for face mounting; spline shaft, per AN-P-11b or keyed shaft with 0.187-in. square keyway.

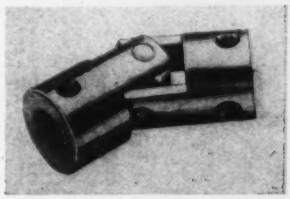
For more data circle MD-6, Page 209

UNIVERSAL JOINTS 7

. . . combine precision and low cost

Kupfrian Mfg. Co., 382 State St., Binghamton, N. Y.

When used in phased pairs, absolute angular fidelity between input and output shafts is claimed to be maintained.



Designation and Size: Type MB-360 and 361; both are 1¼ in. long and ½-in. diam; MB-360 for ¼-in. diam shafts; MB-361 for $\frac{3}{16}$-in. diam shafts.

Service: Coupling shafts whose axes are not in line; have low backlash; meet Army specification 72-53 for 100 hr salt spray resistance; rugged and precise.

Design: Universal joints; brass forks have precision reamed pivot holes and are nickel plated; pivots are ⅛-in. diam, centerless-ground steel; each fork has two 6-32 set-screw holes 90 deg apart for attachment to the shafts.

For more data circle MD-7, Page 209

CABLE HANGERS 8

. . . of molded nylon

Burndy Engineering Co. Inc., Norwalk, Conn.

High strength and resistance to water, oil, gasoline or hydraulic fluids are combined in these cable hangers.

Designation and Size: Nyloclips;

Cat. No.	Diam (in.)	Thickness (in.)	Width (in.)	Mounting Hole Diam (in.)
HP-3N	0.19	0.045	0.375	0.173
HP4N	0.25	0.045	0.375	0.173
HP-5N	0.31	0.045	0.375	0.173
HP-6N	0.38	0.045	0.375	0.173
HP-7N	0.44	0.045	0.375	0.173
HP-8N	0.48	0.045	0.375	0.173
HP-10N	0.59	0.045	0.375	0.173
HP-14N	0.84	0.070	0.500	0.199
HP-18N	1.09	0.070	0.500	0.199
HP-24N	1.47	0.070	0.500	0.199
HP-32N	1.97	0.070	0.500	0.199

Service: Clamping and supporting cables or bundles of cables; resist temperatures from — 60 to 250 F; cannot cause grounds or short circuits; easily installed; noncorrodible.

Design: Cable hangers of molded nylon; 1, 2 and 3 hole tongue types; smooth surfaces protect cable; highly flexible.

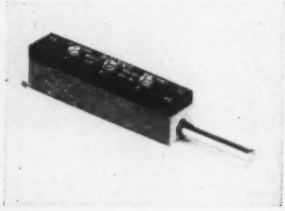
For more data circle MD-8, Page 209

NEW PARTS

LINEAR MOTION POTENTIOMETER 9

. . . is small but accurate

Bourns Laboratories, 6135 *Magnolia Ave., Riverside, Calif.*



Only 2½ in. long, linearity of this potentiometer is ±0.5%.

Designation: Model 108.

Size: ⅝ by ½ by 2½ in.; weighs 1¼ oz.

Service: Varying resistance in proportion to change in position of sliding shaft; resolution of 0.001-in.; resistances from 1000 to 50,000 ohm; will withstand 100 *g* sustained acceleration and vibration of more than 1000 cycles per second; each unit accompanied by calibration record.

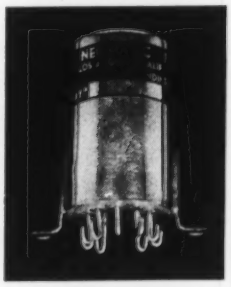
Design: Wire-wound potentiometer; shaft motion is in axial direction; standard shaft travels are $1\frac{5}{16}$, 2¼, 4 or 6 in.; also available with intermediate travels; positive connection between actuator rod and contact assembly.

For more data circle MD-9, Page 209

HERMETICALLY SEALED RELAYS 11

. . . withstand severe conditions

Neomatic Inc., 9010 *Bellanca Ave., Los Angeles* 45, *Calif.*



Hermetically sealed with dry air or inert gas, these relays cannot be harmed by dirt, dust or moisture.

Designation: Model 10220, 10320.

Size: 1 in. diam, 1.71 in. long; weigh 1.51 oz.

Service: 50 to 1000 cycle ac operation at 115 v; 10220 rated 1 amp non-inductive; Model 10320 rated 4 amp non-inductive; optimum operation in temperature range of −55 to 85 C; withstands 20 *g* at 300 cycles per second, 50 *g* steady state acceleration.

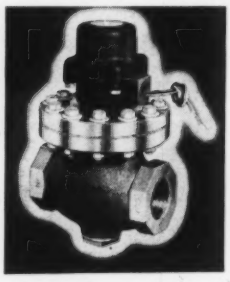
Design: Normally-closed contact relay; connects with 9-hook or 9-pin header; hermetically sealed in dry air or inert gas.

For more data circle MD-11, Page 209

SOLENOID VALVES 10

. . . work at 3000 psi

Atkomatic Valve Co., 545 *Abbot St., Indianapolis, Ind.*



Having only three moving parts and no external linkage, low maintenance is assured.

Designation: Type HP.

Size: ½, ¾, 1 and 1½ in. pipe ports; ½-in. valve is $7\frac{7}{8}$-in. high, $4\frac{1}{16}$ in. long, $4\frac{1}{8}$ in. wide, weighs 10.5 lb; ¾ and 1 in. are $8\frac{13}{16}$ in. high, $6\frac{7}{16}$ in. long, $5\frac{5}{16}$ in. wide, weigh 20 lb; 1½ in. size is 10¾ in. high, 7 in. long, 7 in. wide, weighs 38 lb.

Service: Stopping or starting flow of air, gas, oil, water or steam; operating pressures to 3000 psi except for steam pressure to 250 psi; temperatures to 450 F; coils for any standard ac or dc voltage; bubble-tight for operation where no leakage can be tolerated.

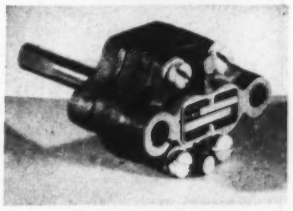
Design: Solenoid controlled, pilot valve operated globe valves; 1½ in. size is all stainless steel, other sizes are navy bronze with stainless-steel springs, pilot valves and valve seats; available with explosion-proof coil housings and for normally-open or normally-closed operation.

For more data circle MD-10, Page 209

GEAR PUMPS 12

. . . have wide range of applications

Webster Electric Co., 1900 *Clark St., Racine, Wis.*



Capacities of ¼ to 2 gpm make these pumps usable for a variety of applications.

Designation and Size: Series LAP and LAS; series LAP are 1⅞ in. wide, 2.140 in. high; series LAS are 2¼ in. wide, 2⅞ in. high; shaft diam, 0.4364 + 0.0003, − 0.0000-in.

No.	Length* (in.)	Length† (in.)	No.	Length* (in.)	Length† (in.)
1 LAP	$1\frac{5}{32}$	$2\frac{3}{32}$	1 LAS	2	$2\frac{13}{16}$
2 LAP	$1\frac{15}{32}$	$2\frac{5}{32}$	2 LAS	$2\frac{3}{16}$	$2\frac{15}{16}$
3 LAP	$1\frac{23}{32}$	$2\frac{5}{16}$	3 LAS	$2\frac{7}{16}$	$3\frac{1}{16}$
4 LAP	$1\frac{31}{32}$	$2\frac{7}{16}$	4 LAS	$2\frac{11}{16}$	$3\frac{5}{16}$
5 LAP	$2\frac{7}{32}$	$3\frac{1}{16}$	5 LAS	$2\frac{15}{16}$	$3\frac{11}{16}$

*Without relief valve †With relief valve

Service: Deliver 0.25, 0.60, 1.00, 1.50 or 2.00 gpm at 1800 rpm at 100 psi with SAE 10 or 1 at 70 F; maximum recommended pressure is 200 psi; speeds in excess of 1800 rpm may be used under certain conditions; relief valve pressures may be varied from 50 to 200 psi.

Design: Gear pumps; alloy steel helical gears; cast iron body; LAP for face or wet sump mounting; LAS for direct gear or belt drive; available with or without integral relief valve; available as 115 or 230 v pump-motor combinations.

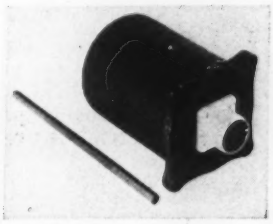
For more data circle MD-12, Page 209

NEW PARTS

OIL-FILLED ACCELEROMETER 13

. . . is extremely resistant to vibration

G. M. Giannini Co. Inc., Bin-N, 254 W. Colorado St., Pasadena 1, Calif.



Output of this accelerometer is high enough so that no amplifying unit is required in most cases.

Designation: 24133.

Service: Varying electrical output in proportion to change in acceleration; ranges up to 30 *g*; resistance ranges of 2000 or 5000 ohm; carries current to 15 ma; resolution of 0.25 per cent accuracy of ±1 per cent; operating temperature range, − 54 to 71 C; has low natural frequency.

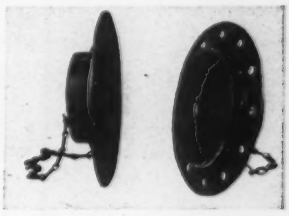
Design: Accelerometer in oil-filled case; potentiometer type resistance varies output; special adaptations available; conduit type electrical connections.

For more data circle MD-13, Page 209

FUEL FILLER CAP 15

. . . for external aircraft fuel tanks

Eaton Mfg. Co., Stamping Div., 18001 *James Couzens Highway, Detroit* 35, *Mich.*



All steel construction provides maximum strength with total weight of only 1 lb 5 oz.

Designation: CM-2432.

Size: 3 in. diam opening.

Service: Provides sealing of tanks at pressures in excess of 25 psi; allows rapid fueling; opens and closes easily; meets all test specifications of MIL-C-7244.

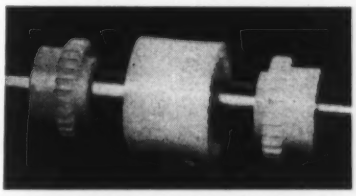
Design: Fuel filler cap and tank adapter; adapter easily conforms to various fuel tank contours; cap fastens to adapter with short length of chain to prevent dropping or losing; closed by 2 revolutions of sealing screw.

For more data circle MD-15, Page 209

GEAR COUPLING 14

. . . for fractional-horsepower drives

John Waldron Corp., New Brunswick, N. J.



Made of nylon, this coupling is unaffected by most liquids and gases.

Designation: Junior.

Size: ⅜, ½, ⅝ and ¾-in. diam bores; all are $2\frac{3}{32}$-in. long and have $1\frac{5}{8}$ in. diam sleeve; weight of ⅜-in. size is 2.17 oz, ¾-in. size is 2.55 oz.

Service: For fractional hp operation; ¾-in. size has been tested at over 1100 lb-in. torque; requires no lubrication.

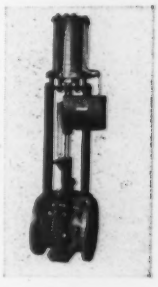
Design: Gear coupling made of nylon; consists of two hubs with external gear teeth and a sleeve with internal gear teeth; hubs fastened to shafts by two set screws spaced 120 deg apart; ⅝ and ¾-in. shaft sizes have $\frac{3}{16}$ by $\frac{3}{32}$-in. keyways in hubs, two smaller sizes have no keyways.

For more data circle MD-14, Page 209

PNEUMATIC CONTROL 16

. . . accurately controls piston position

Foxboro Co., Foxboro, Mass.



Pneumatic cylinder piston position can be regulated within 1% of full stroke.

Designation: Poweractor.

Size: 6 by 7¼ by 3⅝ in.

Service: Accurately positioning pneumatic cylinder piston rod; operates from 3 to 15 psi pneumatic controller signal; will control up to 150 psi; delivers 12 static cfm at 50 psi; case is weatherproof.

Design: Pneumatic control; force balance type, connects to piston rod through bracket and spring; controller signal causes piston rod to move until positioner returns to balanced condition; responds to signal pressure change of ¼ of 1% of total range; ¼ in. pipe ports.

Applications: Controlling valve or damper opening; controlling variable speed drives.

For more data circle MD-16, Page 209

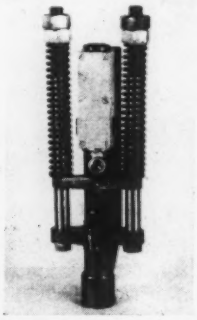
NEW PARTS

PRESSURE SWITCH 17

. . . for service to 3000 psi

Benjamin Lassman & Son, Oliver Bldg., Pittsburgh, Pa.

Ruggedly built, this switch is unaffected by vibration.



Service: Opening or closing electrical circuit; actuation by hydraulic pressure; switch rated 10 amp at 125 v ac; pressure ranges of 200 to 1200 psi and 1000 to 3000 psi available; easily adjustable to operate at any desired pressure within the range.

Design: Hydraulic piston operated switch; when force on piston is great enough to overcome force exerted by two springs, switch is operated; pressure settings made by increasing or decreasing amount of spring compression through tightening or loosening of two nuts, locknuts maintain adjustment; can be mounted in any position.

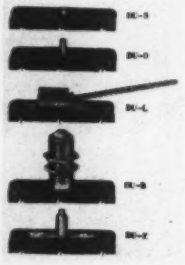
For more data circle MD-17, Page 209

LIMIT SWITCH 18

. . . available with a variety of actuators

General Control Co., 1200 Soldiers Field Rd., Boston 34, Mass.

The same basic switch is available with five different actuators for various types of service.



Designation: DU.

Size: Basic switch is $1\frac{15}{16}$ in. long, $\frac{29}{32}$-in. high and $\frac{11}{16}$-in. wide.

Service: Opening or closing electrical circuits to limit motion; contacts rated at 20 amp 125 v ac noninductive or 10 amp 230 v ac noninductive; low contact bounce and vibration resistance contribute to long life indicated to be in excess of 50 × 10^6 operating cycles by laboratory tests;

Type	Actuating Force (oz.)	Travel to Close Contacts (in.)	Over-Travel (in.)
DU–S	2—6	0.020	0.015
DU–O	2—6	0.020	0.015
DU–L	¾—1¼*	0.250*	0.218*
	½—¾*	0.375*	0.187*
	¼—½*	0.625*	0.125*
DU–B	2—6	0.020	0.062
DU–E	2—6	0.020	0.075

* Leaf actuator is adjustable to three different positions.

Design: Miniature single-pole, double-throw switches; contact blades of phosphor bronze; fine silver contacts; phenolic molded housings; available with nylon or steel plunger, leaf or ball actuators; leaf actuator is adjustable.

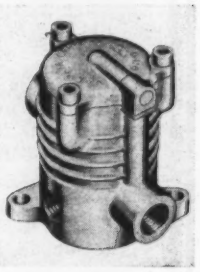
For more data circle MD-18, Page 209

SOLENOID PILOT VALVE 19

. . . controls air, vacuum, oil or water

Valvair Corp., 454 Morgan Ave., Akron 11, O.

Only two moving parts, plunger and stem, assure long life.



Size: 3 in. high; ¼-in. female pipe ports; $\frac{1}{16}$, $\frac{3}{32}$ or ⅛-in. diam orifices.

Service: Controlling pilot-operated valves; maximum working pressure is 150 psi for $\frac{1}{16}$-in. orifice; 90 psi for $\frac{3}{32}$-in. orifice; 60 psi for ⅛-in. orifice; maximum power consumption of solenoid is 10 w; solenoid coils 110, 220, 440 v ac 60 cycle and all standard dc voltages; for continuous or intermittent service.

Design: Solenoid-operated pilot valve; body and cover of high-tensile zinc-base alloy; one-piece, unbreakable stem; sealed by Hycar O-rings; available as 2 or 3-way model, normally-open or normally-closed; may be drilled through the bottom for manifold mounting; mounting lugs are integral with valve body.

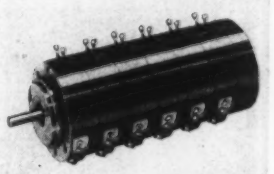
For more data circle MD-19, Page 209

GANGED POTENTIOMETERS 20

. . . have no external clamping devices

G. M. Gianinni Co. Inc., 254 W. Colorado St., Pasadena, Calif.

Life of these units is 250,000 or more shaft revolutions at 100 rpm.



Designation: Gangpot type 85194.

Size: Length of 4-section unit including shaft extension is approximately $5\frac{1}{16}$ in., 2.475 in. diam; weight is 5 oz or less per section in units of more than 3 sections; nominal ¼-in. shaft diam.

Service: Varying from 2 to 6 electric currents or voltages simultaneously; each section may be adjusted through an angle of 22 deg with an accuracy of 0.2 deg for correct phasing; resistance values from 2000 to 300,000 ohm per section; accuracy of resistance ± 5% operates at ambient temperatures of − 54 to 71 C; each section will dissipate 2 w at 71 C ambient temperature or 4 w at 25 C; 500 v breakdown rating; linear wound types have linear output within ± 3% of total resistance; withstands 50*g* acceleration.

Design: Wire wound, ganged, precision potentiometer; housings of anodized aluminum; continuous shaft rotation; shaft of precision-ground stainless steel; electrical angle of rotation is any desired value to 360 deg; shaft supported by shielded ball bearings; synchro or face mounted; optional rear shaft extension; solder hook terminals fused in glass; one or two brushes and up to 10 resistance taps available.

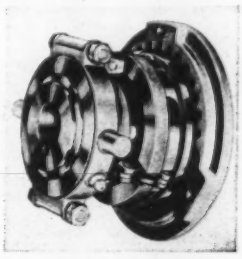
For more data circle MD-20, Page 209

NEW PARTS

SINGLE DISK CLUTCHES 21

. . . for light machinery service

Carlyle Johnson Machine Co., Manchester, Conn.



Adjustment, when necessary, is easily made without special tools by tightening a knurled adjusting ring.

Designation and Size: No. 350, 3 hp max, for ¾, ⅞, 1, or 1 1/16 in. diam shafts; No. 450, 6 hp max, for 1⅛, 1 3/16 or 1¼ in. diam shafts.

Service: Engaging or disengaging driving and driven members; No. 350 rated at 13 lb-ft working torque; No. 450 rated at 27 lb-ft working torque; for dry operation; no drag or heating when disengaged; long clutch disk facing life.

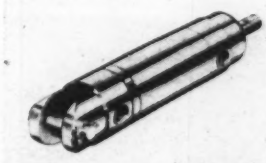
Design: Single-disk clutches; available with gear-tooth type drive for bolting to gears, sprockets or sheaves and for single or double V-belt drive, all models have ¼ by ⅛-in. keyways for keying to driven shafts or keyway as required for a particular application; clutch disk facings are composition friction material.

For more data circle MD-21, Page 209

AIR CYLINDERS 22

. . . save mounting space

Tomkins-Johnson Co., Jackson, Mich.



Having circular heads and no tie rods, these cylinders provide mounting space savings as high as 40 per cent.

Designation: Spacemaker.

Size: 1 in. bore, 2 1/16 stroke; 1½ in. bore, 3 3/16 in. stroke; 2 in. bore, 3 5/16 in. stroke; stroke; 2½ in. bore, 3 5/16 in. stroke; 3 in. bore, 3 11/16 in. stroke; 4, 5, 6 and 7 in. bore, 4½ in. stroke; 8 in. bore, 4⅝ in. stroke.

Service: Pushing, pulling or lifting; leakproof; has high strength; high speed and power with minimum friction loss; long life and high safety factor.

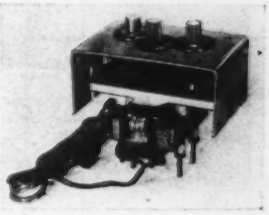
Design: Pneumatic cylinders; steel head and seamless steel bodies; bores precision honed; high tensile strength, hard chrome plated piston rod; self-adjusting piston rod packing; metallic piston rod wiper ring; available for foot, flange, swivel, trunnion or rabbet mounting; may be flange-mounted at either end.

For more data circle MD-22, Page 209

MIDGET GEARMOTORS 23

. . . are dependable and sturdy

General Die and Stamping Co., 262 Mott St., New York 12, N. Y.



Midget unit draws only 15 watts.

Designation: Kasson Roto-Sho.

Size: 3¼ by 4⅝ by 3¼ in.; shaft diam is 7/16-in.; shaft extension ½-in.

Service: Operate on 110 to 120 v ac at 50 to 60 cycles; output speeds 1 to 1150 rpm; long-lived with little maintenance; high torque at low or medium speeds.

Design: Shaded pole induction gearmotors; bearings are self-aligning, oil-retaining type; available in semienclosed or open types; gears of metal or fiber, oversize brass pinions; plates of heavy gage steel; can be supplied with multiple output shafts if desired.

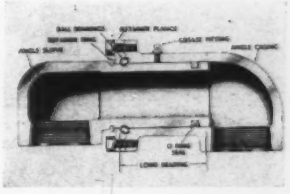
Applications: Electric control drives; valve controls; remote control devices.

For more data circle MD-23, Page 209

SWING JOINTS 24

. . . for loading and unloading lines

Barco Mfg. Co., Dept. J-6, 1801 W. Winnemac Ave., Chicago 40, Ill.



Will work from −30 to 250 F at pressures to 1500 psi.

Size: 2, 2½, 3 and 4 in. pipe.

Service: Swinging 360 deg in one plane or in two planes at right angles; for gasoline, oil, diesel, fuel, air, oxygen, water, alcohol and hydrocarbons such as ethyl ether; maximum pressure rating of 1500 psi is for 2 in. size handling hydraulic fluid in static service, pressure ratings are lower for larger sizes and other media; easily disassembled for seal replacement.

Design: Ball-bearing swing joints sealed by O-rings; grease fitting for lubrication of bearing; standard joints of steel; eleven styles available, single or double swing, straight or angle types; available as specials in materials other than steel.

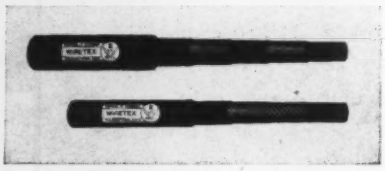
For more data circle MD-24, Page 209

NEW PARTS

HIGH-PRESSURE HOSE 25

. . . will withstand 5500 psi

Republic Rubber Div., Lee Rubber & Tire Corp., Youngstown 1, O.



Flexibility, oil and abrasion resistance characterize this reinforced hose.

Designation: Wiretex.

Size: $\frac{3}{16}$ to 2 in. diam; lengths to 60 ft.

Service: Carrying hydraulic oil, steam, air, ammonia and other fluids; for pressures to 5500 psi; withstands temperatures from −40 to over 200 F; highly oil resistant; not weakened by vibration or flexing; flow volume not affected by pressure surges.

Design: High-pressure hose; composed of mandrel cured Reprene tube reinforced with rubber-impregnated textile and braided fabric plies and braided wire plies or with multiple plies of standard or extra heavy wire only; outer covering of thick rubber or braided textile.

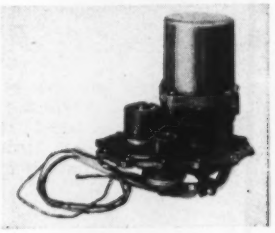
For more data circle MD-25, Page 209

WATER INJECTION PUMP 27

. . . uses turbine wheel instead of vanes

Romec Div., Lear Inc., Elyria, O.

Use of a turbine wheel rather than previous rotary-vane pumping element has reduced size and weight by 25%.



Designation: Model RR-9700.

Size: 6¾ in. long, 4⅞ in. wide and 7⅛ in. high; weighs 4.75 lb.

Service: Supplying antidetonant solution under pressure for aircraft engines; rated 110 gph at 35 psi; integral driving motor is ¼-hp, 200 v ac, 3-phase, 400-cycle; pump parts unaffected by corrosive antidetonant solution.

Design: Turbine pump driven by integral electric motor; mounting flange to AN 4135 for mounting on bottom of tank with pump inside; explosion-resistant cover on motor; pump inlet strainer accessible through clean-out plug in flange; turbosupercharger and sealed in ports are $\frac{7}{16}$-20 NF-3 thread, discharge port is ¾-16 NF-3; 4 electrical leads are 14 in. long, have quick-disconnect self-locking connectors.

For more data circle MD-27, Page 209

DISCONNECT SWITCHES 26

. . . can be used as load interruptors

Delta-Star Electric Co., Div. of H. K. Porter Co. Inc., 2437 Fulton St., Chicago 2, Ill.

Tests have shown that these switches will safely interrupt currents much higher than rated values.

Designation: Dis-ruptor.

Size: Cabinet of three-pole, 600 amp switch with fuses is 58 in. high, 16 in. deep and approximately 27 in. wide.

Service: Interrupting 400, 600, 1200, 2000 or 3000 amp at 600 v ac or dc, safely and positively; positively extinguishes arcs; long contact surface life; weathertight enclosure excludes dust and moisture; fast opening and closing of contacts.

Design: 2 or 3 pole interrupter or disconnect switches; 10-gage steel cabinets have continuously welded seams and weathertight door gaskets; quick-make and break toggle mechanism; high impact molded phenolic insulators, interlock prevents opening of door with switch closed; door can be locked shut; switch can be padlocked in open or closed position; available with or without provisions for fuses.

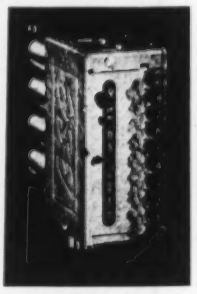
For more data circle MD-26, Page 209

COUNTING UNIT 28

. . . produces output pulse at preset count

Berkeley Scientific Div. of Beckman Instruments Inc., 2200 Wright Ave., Richmond, Calif.

When a preset count is reached the output pulse produced can initiate any desired action and reset the counter to zero.



Designation: Model 730.

Size: 3¼ by 5½ in.; weighs 1 lb 5 oz.

Service: Counting electrical pulses at rate of 40,000 per second and producing 200 v output pulse when preset count is reached; units may be cascaded to achieve desired maximum count; count is displayed on front of unit; requires 6.3 v at 2.1 amp for tube filaments, 3000 v dc at 15 ma for plates and −150 v dc at 2 ma; input pulses must have 90 v peak amplitude, at least 1 microsecond rise time and duration of 2 microseconds; resolves pulses, separated by as little as 5 microseconds.

Design: Electronic counter consisting of four cascaded binaries permuted to a scale of ten, a four tube coincidence amplifier and a ten pole switch; unit plugs into 11 pin socket.

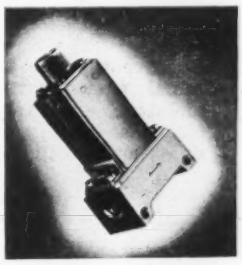
For more data circle MD-28, Page 209

NEW PARTS

SOLENOID VALVE 29

. . . has self-cleaning seal disks and seats

Valcor Engineering Corp., 314 *Market St., Newark* 5, *N. J.*



Since the valve seat is always wiped clean as the valve operates, sand, filings, chips and dirt do not interfere with operation.

Size: ¼ or ⅜-in. OD tube sizes.

Service: Controlling fluid flow; maximum working pressure of 120 psi; coil for 18 to 30 v dc; can be used in ambient temperatures to 200 F; coil is impervious to vibration and shock; tests show life of more than 2×10^6 operating cycles; will handle jet fuel, aromatics and highly corrosive media; low pressure drop.

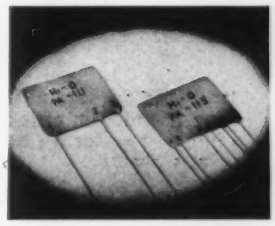
Design: Solenoid-operated, normally-closed valve; coil insulation is Class H; self-lapping seal disk of carbon graphite; all parts which contact fluid are stainless steel or aluminum; symmetrical about center, flow may be in either direction.

For more data circle MD-29, Page 209

PLATE ASSEMBLIES 31

. . . electronic circuit elements in small sizes

Hi-Q Div., Aerovox Corp., Olean, N. Y.



A typical assembly combines six capacitors, four resistors and all connections in a small flat plate measuring 1⅛ by ⅜ by $\frac{5}{32}$-in.

Designation: PA.

Size: All are $\frac{5}{32}$-in. thick, length and width vary with complexity of circuit.

Service: Typical circuits are vertical integrator, vertical integrator and coupler, audio plate grid coupler, second detector and audio amplifier coupler and pentode plate coupler and screen supply; eliminate assembly and soldering time; reduce number of leads to be connected.

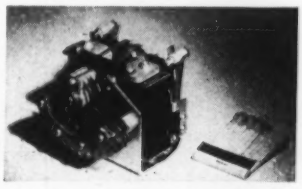
Design: Printed circuits on high dielectric base plates; completely embedded in ceramic material; circuits consist of resistors, capacitors and all necessary connections between them; available in a variety of circuits other than those mentioned; wire leads are solid No. 24 AWG wire.

For more data circle MD-31, Page 209

STEPPING SWITCH 30

. . . has a variety of applications

Consolidated Engineering Corp., 300 *N. Sierra Madre Villa, Pasadena, Calif.*



Self-interrupted completely reversible operation make this switch applicable in many types of differential counter and servo-mechanism designs.

Designation: Model 27000.

Size: 2⅞ in. wide, 2⅝ in. deep, 2⅝ in. high; weighs 21 oz.

Service: Advances or reverses with equal ease and speed in steps of 10 deg, 36 discrete positions, cannot be positioned between steps; 650 ohm coil for 110 to 125 v dc operation, current drain 50 ma; speed 60 to 65 steps per second; typical switch transfers four parallel circuits to 12 positions.

Design: Stepping switch; two opposed, completely separated driving armatures and coils operate on a common ratchet to step shaft in either direction; driving coil locks in energized condition until step is completed; limit switches disconnect coil on completion of step; driving parts case-hardened except driving pawl which is heat-treated, high-alloy tool steel; electrical springs of beryllium copper or spring bronze are actuated by nylon rollers.

For more data circle MD-30, Page 209

COAXIAL CONNECTOR 32

. . . for miniature electronic assemblies

Microdot Div., Felts Corp., 1826 *Fremont Ave., South Pasadena, Calif.*

Connectors only 0.220-in. in diam and 0.85-in. long make this connector-cable assembly ideal when small size is essential.

Size: 0.220-in. diam, 0.85-in. long; 10-32 mounting threads; cable lengths to 3 ft.

Service: Usable to 1000 megacycles with minimum insertion loss; rated at 600 v rms; characteristic impedance is 50 ohm or more; loss for 3 ft. of cable and 2 complete male and female connectors is 0.9 db at 400 megacycles; usable temperature range of − 65 to 300 F; vibration and moisture resistant; low self-generated noise.

Design: Miniature coaxial cable and connectors; single-hole mounting on panel or chassis of mating members; Teflon insulation used on both cable and connectors; O-ring seals used on connectors; cable treated with conductive materials; chassis or panel feed-through couplings available.

For more data circle MD-32, Page 209

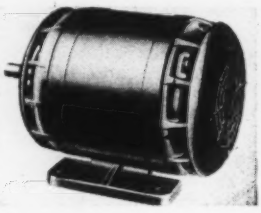
NEW PARTS

ELECTRIC MOTORS 33

. . . deliver high power with low weight

Baldor Electric Co., 4353 Duncan Ave., St. Louis 10, Mo.

Steel stator laminations are embedded in cast aluminum to form lightweight frame.



Designation: Baltric.

Size: Fractional and integral hp.

Service: Deliver higher hp than previous motors of same NEMA frame sizes; will operate in any position; withstand relatively high ambient temperatures.

Design: Single and polyphase motors; squirrel cage rotors cast of aluminum and dynamically balanced; end frames of cast iron; ball bearings lubricated and sealed; provision made for removal of old grease and addition of new; one aluminum cooling fan at each end of motor; fan guards of sheet steel; mounting base detachable to permit use of special bases when required.

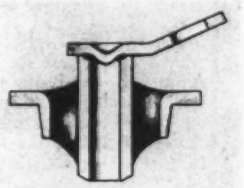
For more data circle MD-33, Page 209

FEED-THROUGH TERMINAL 35

. . . conducts current into sealed enclosures

Fusite Corp., Cincinnati, O.

Construction of this terminal prevents accidental violation of hermetic enclosures during soldering of external lead wire.



Size: Internal extension is $\frac{1}{8}$-in., external extension is $\frac{5}{32}$-in.; $\frac{3}{64}$-in. mounting hole diam; $\frac{1}{16}$-in. diam hole in external soldering lug; takes up to 17 gage wire internally.

Service: Gas tight; easily attached by soft-soldering; soldering lug will absorb impacts which might damage terminal; insulates electrical connections from metal enclosures.

Design: Feed-through terminal of glass and steel permanently fused; external soldering lug welded to hollow tube; lug may be bent up to 90 degrees to facilitate attachment of external wire.

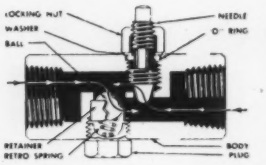
For more data circle MD-35, Page 209

FLOW CONTROL VALVES 34

. . . for pneumatic or hydraulic control

Pneu-Trol Devices Inc., 1436 N. Keating Ave., Chicago 51, Ill.

Precise control of cylinder speeds is made possible by these valves.



Designation and Size:

Valve No.	Pipe Size (in.)	Hex Size (in.)	Length (in.)
100	$\frac{1}{8}$	0.625	1.750
200	$\frac{1}{4}$	0.875	2.375
250	$\frac{3}{8}$	1.062	2.750
300	$\frac{1}{2}$	1.312	3.187
350	$\frac{3}{4}$	1.625	3.562

Service: Controlling rate of flow of air or hydraulic fluid in one direction and allowing full flow in opposite direction; rated at 2000 or 5000 psi dependent upon valve material; will not leak; corrosion-resistant models available.

Design: Combination ball-check and needle valve; flow in one direction is through needle valve orifice, flow in other direction through needle valve and check valve orifices; of steel, stainless steel, brass or aluminum; female pipe threads are made to Dryseal specifications; needle valve stem flatted and provided with locknut.

For more data circle MD-34, Page 209

SWITCHES 36

. . . actuated by small forces

Micro Switch, Div. of Minneapolis-Honeywell Regulator Co., Freeport, Ill.

A force of only $\frac{1}{2}$-oz is required to operate one of these switches.

Designation: W80, W82, W822.

Size: Basic switch is $1\frac{13}{16}$ in. long, $\frac{13}{16}$-in. wide and $1\frac{3}{64}$ in. high; overall dimensions vary with actuator.

Service: Opening or closing electrical circuits; rated at 15 amp at 125, 250 or 460 v ac, $\frac{1}{2}$ amp at 125 v dc, $\frac{1}{4}$ amp at 250 v dc; actuating force varies from $\frac{1}{2}$-oz to 7 oz dependent upon type of actuator; for use in devices requiring low operating force.

Design: Miniature snap-action switches with flat lever, long lever and roller and short roller and lever actuators; switch is single-pole double-throw type; available with solder or screw type terminals; also available in single-pole, single-throw contact arrangement with normally open or normally closed contacts.

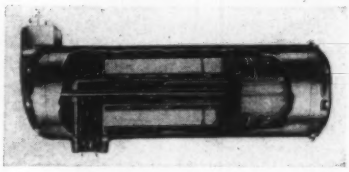
For more data circle MD-36, Page 209

NEW PARTS

HYDRAULIC SYSTEM FILTER 37

. . . has built-in shut-off valve

Rucker Mfg. Co., 4516 *Hollis St., Oakland* 8, *Calif.*



The built-in shut-off valve permits filter element changes without draining the hydraulic system.

Designation: No. 2.

Size: 8 in. diam, 25½ in. long; 2 in. pipe ports.

Service: Removing foreign material from hydraulic oil; has high flow rate with low pressure drop; with 24 gpm flow of 210 Saybolt universal second oil at 90 F pressure drop is 1 psi through 25-micron filter element, approximately 1.7 psi through 6-micron element.

Design: Replaceable element type filter; can be mounted in hydraulic oil tank with head exposed or mounted externally; shut-off valve permits element changes without draining; standard replacement filter elements used.

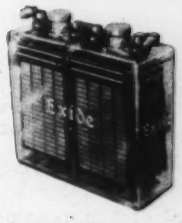
For more data circle MD-37, Page 209

STORAGE BATTERIES 39

. . . weigh less per ampere-hour output

Electric Storage Battery Co., Box 8109, *Philadelphia* 1, *Pa.*

Lightweight, clear polystyrene cases have high resistance to shock and thermal stresses.



Designation: Tytex Type COE.

Size: All 8½ in. high, 8 in. wide (end to end) or 4¼ in. wide (side-to-side).

Service: For stationary low power service; approximately 2 v dc per cell; capacities from 8 to 30 amp-hr at 8 hr. rate; necessary to add water only once or twice a year; low internal resistance and high capacity; long trouble free service.

Design: Lead-sulfuric acid storage batteries; cases of clear polystyrene; three insulating layers between plates, microporous rubber, slotted polystyrene and Vitrex; colored balls in case indicate specific gravity of electrolyte or state of charge; lines on case indicate upper and lower limits of correct electrolyte level.

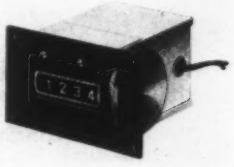
For more data circle MD-39, Page 209

ELECTRIC COUNTER 38

. . . for panel mounting

Production Instrument Co., 702-08 *W. Jackson Blvd., Chicago* 6, *Ill.*

Low operating power permits operation of this counter in the plate circuit of a vacuum tube.



Designation: MDB-54.

Size: $2\frac{3}{16}$ in. wide, $1\frac{1}{16}$ in. high, $2\frac{3}{32}$ in. deep; requires $2\frac{3}{16}$ by $1\frac{1}{16}$ in. opening for mounting.

Service: Counting electrical impulses; power consumption 2 w at 6, 12, 24, 48 and 115 v dc or 60 cycle ac; rated at 600 counts per minute but has operated in plate circuit of vacuum tube at 1800 counts per minute maximum count 9999; easily reset; easily readable.

Design: Electrical counter; operates satisfactorily in any position; may be operated by any switch or relay with minimum closed and open periods of 0.040 second or by vacuum tube with output of 3 w or more; 6 in. wire leads through side or bottom, as required; large white figures on black number wheels; also available for 25 or 50 cycle ac.

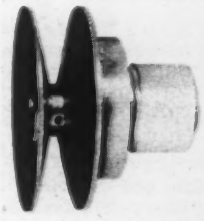
For more data circle MD-38, Page 209

VARIABLE SPEED PULLEY 40

. . . for fractional horsepower motors

Gerbing Manufacturing Corp., 11800 *Milwaukee Ave., Northbrook, Ill.*

Used with an adjustable motor base, this pulley gives speed variation of 2¾ to 1.



Designation: Var'A'Cone No. 50.

Size: $5\frac{1}{16}$ in. diam, $3\frac{29}{32}$ in. long; bored for ½, ⅝ or ¾-in. diam shafts.

Service: Varying speed of rotation of driven shaft; uses standard "A" belt; requires no lubrication; max motor speed, 1750 rpm; rated ¾-hp at 1750 rpm, ½-hp at 1160 rpm; max pitch diam is 4.75 in., min is 1.73 in.

Design: Variable speed pulley; consists of stationary disk, inner sliding disk, outer sliding disk, spring and spring cover; as motor is moved toward or away from driven shaft, pitch diam changes automatically; all belt contacting surfaces are smooth; parts machined from cast iron; oil impregnated bushings; base for motors to NEMA frame No. 203 available.

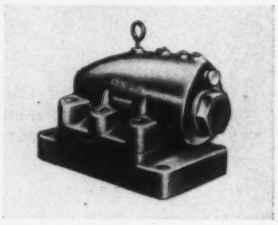
For more data circle MD-40, Page 209

NEW PARTS

RELIEF VALVE 41

. . . controls pressures to 5000 psi

Denison Engineering Co., 1160 *Dublin Road, Columbus* 16, *O.*



Exceptionally low differential between opening and closing pressures results in close pressure control.

Size: 2 in. pipe ports.

Service: Controlling hydraulic system pressure by bypassing oil to reservoir when desired pressure is exceeded; capacity 125 gpm; pressure settings easily adjusted or varied at valve or from remote location; leakage is almost zero.

Design: Relief valve; all sealing surfaces very closely fitted; knurled pressure adjusting screw on valve cap; with threaded body or for subplate mounting.

For more data circle MD-41, Page 209

ELECTRIC GENERATORS 42

. . . have no brushes

Georator Corp., 1820 *N. Nash St., Arlington* 9, *Va.*

Brushless construction makes these generators immune to damage by moisture, overload or short circuit.

Designation: Nobrush.

Size and Service: Generating 120 v 400 cycle ac;

Rating (kva)	Speed (rpm)	Length (in.)	Height (in.)	Width (in.)	Weight (lb.)	Phase (No.)
0.25	3428	5⅛	7½	7	8	1
0.40	3428	5⅛	7½	7	8	3
0.50	3428	10¼	7½	7	12	1
0.50	1714	7	11¼	10½	22	1
0.75	3428	10¼	7½	7	12	3
1.00	1714	7½	11½	10½	30	1
1.00	1714	7	11¼	10½	23	3
2.00	1714	7½	11½	10½	32	3
2.50	1714	10½	16	16	53	1
5.00	1714	13	16	16	60	1
5.00	1714	10½	16	16	56	3
10.00	1714	13	16	16	63	3
15.00	1714	16	22	20	195	1
25.00	1714		22	20	210	3

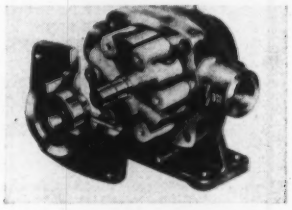
Design: Electric generator with cast-aluminum rotor containing permanent magnets which eliminate brushes and commutator; only wearing parts are shaft bearings; available for direct engine or motor mounting; shielding retains magnetism indefinitely, generators show change in terminal voltage of less than a fraction of a per cent after long use; also available in 25, 50, 60, 180, 360, 800 and 900 cycle types.

For more data circle MD-42, Page 209

ROLLER-TYPE PUMP 43

. . . for erosive mixtures

Hypro Engineering Inc., 404 *N. Washington Ave., Minneapolis* 1, *Minn.*



Nylon rollers insure positive liquid displacement and long life.

Designation: Series 6000.

Size: ¾-in. pipe ports; weighs 10½ lb.

Service: Pumping erosive mixtures such as wettable powder solutions; delivers 12.5 gpm at 800 rpm, open discharge; max recommended speed, 800 rpm; recommended max pressure, 200 psi.

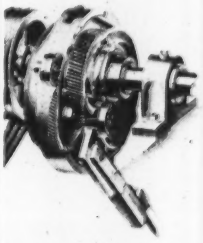
Design: Roller-type pump; nylon rollers; rotor and housing of Ni-Resist or cast iron; stainless steel shaft; permanently lubricated ball bearings; can be mounted on PTO shaft or on base plate for belt and pulley drive.

For more data circle MD-43, Page 209

SPEED REDUCERS 44

. . . mount on driven shaft

American Pulley Co., 4200 *Wissahickon Ave., Philadelphia* 29, *Pa.*



Overall efficiency of approximately 96 per cent results from the use of helical gears, antifriction bearings and antifriction sealing.

Designation and Size:

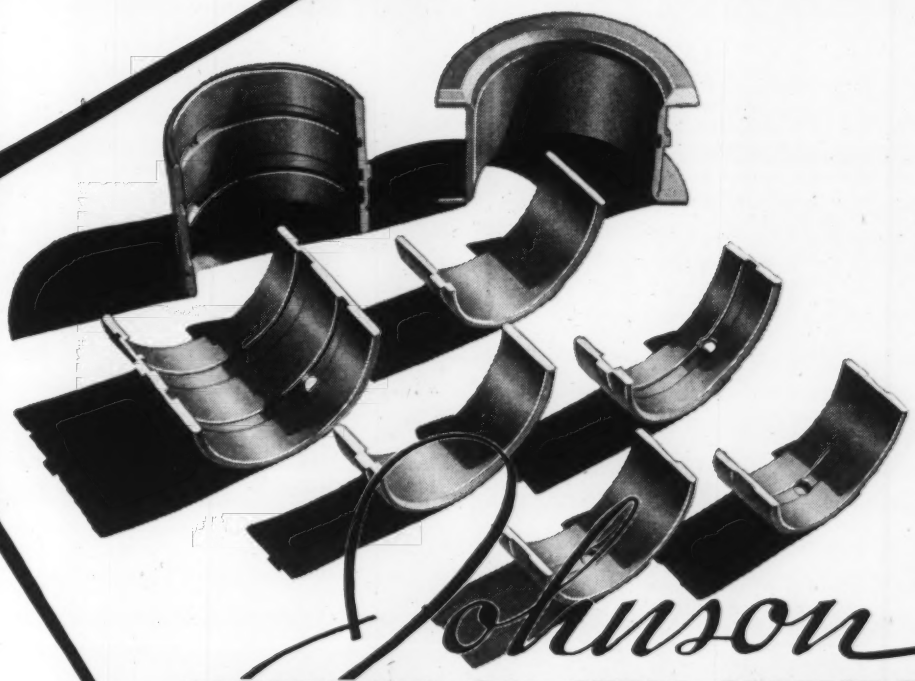
No.	Diam. (in.)	Overall Length (in.)	Input Shaft Diam (in.)	Output Bore Diam (in.)
020	9¼	$7\frac{31}{32}$	¾	$1\frac{7}{16}$
120	11¾	$9\frac{3}{16}$	1⅛	2
220	$13\frac{7}{16}$	11	1¼	$2\frac{3}{16}$
320	15¼	$12\frac{11}{16}$	$1\frac{7}{16}$	$2\frac{7}{16}$
420	$17\frac{7}{16}$	$14\frac{3}{16}$	$1\frac{11}{16}$	$2\frac{11}{16}$
520	20½	$15\frac{7}{8}$	$2\frac{3}{16}$	$3\frac{7}{16}$
620	23½	19½	$2\frac{7}{16}$	$3\frac{11}{16}$

Service: Reducing speed; reduction ratio is 20/1; will transmit up to 42 hp; max recommended output speed, 90 rpm; easily installed and removed.

Design: Speed reducer for mounting on driven shaft; requires shaft length of 2 diam plus clearance for mounting; input shaft and output hub on same axis; housing machined of cast iron, internally ribbed for strength; gears and pinions of flame hardened alloy steel; torque arm prevents rotation of reducer.

For more data circle MD-44, Page 209

Perfected at Last!



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These roll-bonded Aluminum-on-Steel Bearings may be used for loads up to 4000 P.S.I., yet have good conformability, good resistance to shaft wear, good resistance to corrosion, adequate seizure resistance and good resistance to fatigue. Tests prove that the bond to the steel back is as strong as the metal itself. These properties make Johnson Aluminum-on-Steel Bearings new high-load, high-speed bearings with a great future for high-load internal combustion engines. Write for full information.

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JOHNSON JB BEARINGS
Sleeve-Type

Sleeve Bearing Headquarters Since 1901

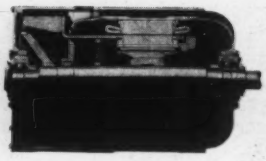
NEW PARTS

HIGH-SLIP MOTORS 45

. . . for acceleration of high inertia loads

General Electric Co., Small and Medium Motor Dept., Schenectady 5, N. Y.

New design for more efficient heat dissipation makes these motors 40 per cent lighter than previous high-slip motors.



Designation: Type KRX.

Size: 30 to 150 hp.

Service: Voltage ratings of 220, 440 and 550 v; speed rating 900 or 1200 rpm; 5 to 8 or 8 to 13 per cent slip ratings.

Design: Induction motor; totally enclosed and fan cooled; low resistance rotor bars are extended at one end of rotor and pass through a rotating baffle plate, strips of high-resistance metal are brazed to the ends of the bars to form a radial-blade fan; most of rotor heat develops in high-resistance metal outside motor enclosure where it is transferred directly to cooling air; this construction allows use of normal air gap.

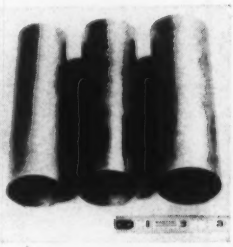
For more data circle MD-45, Page 209

SEAMLESS TUBING 47

. . . now available in larger sizes

Superior Tube Co., Norristown, Pa.

Previously available only to 1¼ in. OD, this seamless light-wall tubing can now be obtained to 2⅛ in. OD.



Form: Seamless tubing.

Size: Up to 2⅛ in. OD; wall thicknesses of 0.010 to 0.025-in. for 1½ to 2⅛ in. OD; wall thicknesses 0.010 to 0.035-in. for 1¼ to 1½ in. OD; lengths 5 to 22 ft in random, multiple or cut lengths.

Service: For relatively high-pressure applications requiring thin walled tubing; withstands higher pressures than welded tubing of same wall thickness; withstands corrosion.

Properties: Tubing of AISI type 304, 321 or 347 stainless steel or Monel; pickled or standard bright finish; in three tempers, fully annealed, half-hard drawn or full-hard drawn; OD tolerances of + 0.010, − 0.000-in; wall thickness tolerance ± 10%.

Applications: Food and chemical processing; heat exchanger tubes; bellows; metal hose.

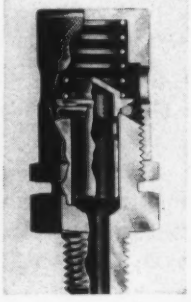
For more data circle MD-47, Page 209

RELIEF VALVES 46

. . . have long life without leakage

James-Pond-Clark Co., 2181 E. Foothill Blvd., Pasadena 8, Calif.

Tests indicate life of over 7,000,000 operating cycles.



Designation: Series 5400.

Size: ⅛ or ¼-in. male pipe.

Service: Preventing excessive pressures in gas systems where gases such as nitrogen or carbon dioxide can safely be released to the atmosphere; opening pressures of 2 to 45 psi; operating temperature range 40 to 280 F.

Design: Relief valve of aluminum or brass; plunger is sealed by standard O-ring for pressures from 2 to 6 psi and by O-ring and metal back-up ring at higher pressures; O-ring is self-aligning between two conical seats; also available in other materials and pipe sizes; available for temperatures from − 80 to 400 F as specials.

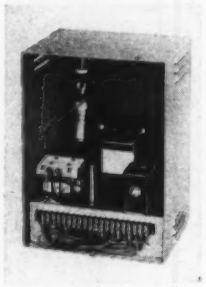
For more data circle MD-46, Page 209

VARIABLE SPEED CONTROL 48

. . . has range of 100 to 1

Arrow-Hart & Hegeman Electric Co., 103 Hawthorn St., Hartford 6, Conn.

Speed variation of 35 to 3500 rpm is possible with the optional dual-range feature.

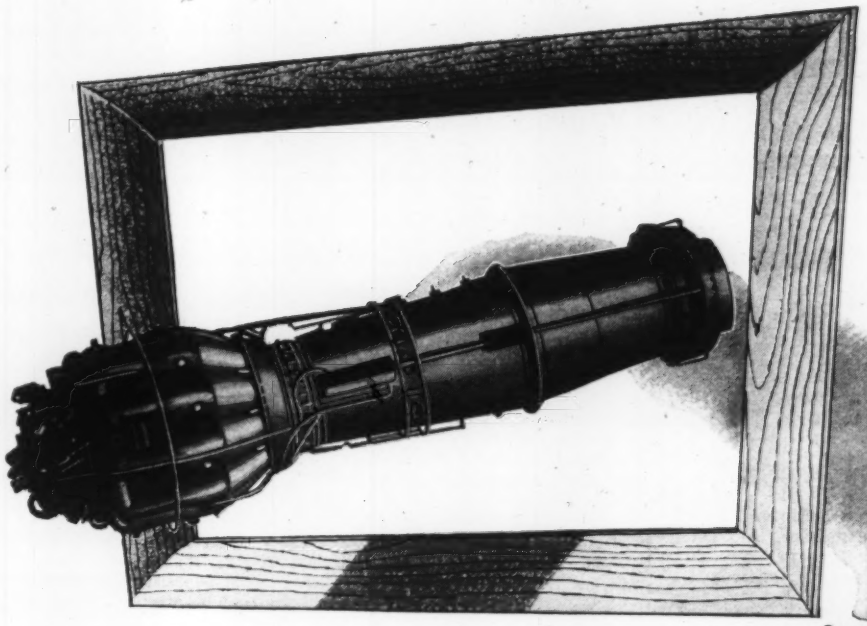


Size: For fractional hp motors.

Service: Starting, stopping and varying speed of fractional hp dc series motors; supply voltage is single-phase 230 v 60 cycle ac; operates at ambient temperatures of 0 to 110 F; will maintain substantially constant speed with varying load; long control life due to low current requirement of dc series motor; high torque at low speeds and high speed at medium torque; normal speed range, 100 to 3500 rpm.

Design: Single-tube, half-wave rectifier controlled by phase shifter; push-pull selector switch with 16 possible positions; NEMA Type 1 general purpose enclosures; full compensation for varying line voltage available; other types of switches available; auto transformers for other supply voltages available.

For more data circle MD-48, Page 209



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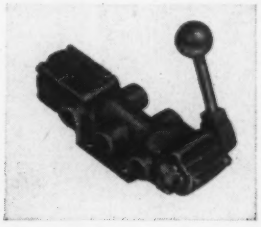
NEW PARTS

CONTROL VALVES 49

. . . may be serviced without disconnecting

Versa Products Co. Inc., 249 *Scholes St., Brooklyn, N. Y.*

Complete disassembly and assembly are possible using only a screwdriver.



Size: ⅛ or ¼-in. pipe ports; four-way pilot operated valve is 6 in. long, 2 in. wide and 1⅝ in. high.

Service: Controlling hydraulic or pneumatic devices; maximum recommended operating pressure, 200 psi; service life in excess of one million operating cycles; low actuating force required; corrosion resistant.

Design: Two, three, or four-way valves; cam, pilot valve, foot-treadle or hand operated; balanced pressure spools used in all valves; bodies and caps of bronze; internal parts of brass; standard O-ring seals used; all valves available with or without spring return to normally open or closed position when actuating force is removed.

For more data circle MD-49, Page 209

V-LINK BELTING 51

. . . of improved material

Brammer Corp., 684 *Broadway, New York* 12, *N. Y.*

New natural rubber compound increases flexibility and facilitates assembly.

Size: ⅜, ½, ⅝, ⅞ and 1¼ in., same as standard O, A, B, C and D V-belts.

Service: Power transmission; can be used in place of endless V-belts; long service life; extremely flexible; any length easily made up; easily installed.

Design: Power transmission belts made up of links held together by studs; links are rubber-impregnated duck; stud bonded into each link; belts assembled from links without tools; letter embossed on head of each stud shows size of corresponding V-belt; all belting pre-stretched at factory.

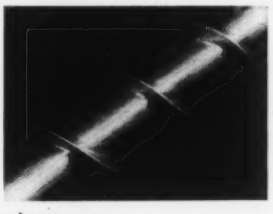
For more data circle MD-51, Page 209

SCREW CONVEYOR 50

. . . of stainless steel

M-H Standard Co., 515 *Communipaw Ave., Jersey City* 4, *N. J.*

Available in two styles, for industrial or sanitary applications such as food processing.



Designation: Industrial and Saniscrew.

Size: 6 in. diam, 9 ft 10 in. lengths.

Service: Conveying bulk material; resists corrosion and abrasion.

Design: Screw conveyor of type 304 stainless steel; ⅛-in. thick flights are welded to 2 in. diam pipe; pipe is bushed and drilled for 1½ in. diam coupling shafts; Industrial style has mill or No. 2B finish with flights welded to pipe at regular intervals; Saniscrew style is polished to No. 4 finish and flights are continuously welded to pipe; weld is ground and polished to give smooth sanitary fillet; can be made of monel, nickel, aluminum, bronze or steel as specials.

For more data circle MD-50, Page 209

PULSE TRANSFORMER 52

. . . slightly smaller than a pea

PCA Electronics Inc., 6368 *De Longpre Ave., Hollywood* 28, *Calif.*

Ideal for miniature assemblies, this transformer works equally well in conventional circuits.

Designation: MPT 101-0.1.

Size: Weighs 0.03 oz.

Service: Pulse forming or pulse coupling; 0.1 microsecond pulse width and rise time of less than 0.005 milli-microseconds when used in recommended circuits; operates indefinitely at − 70 to 125 C, will operate for short time at 150 C; meets all MIL-T 27 test specifications; leads will withstand 5 lb pull.

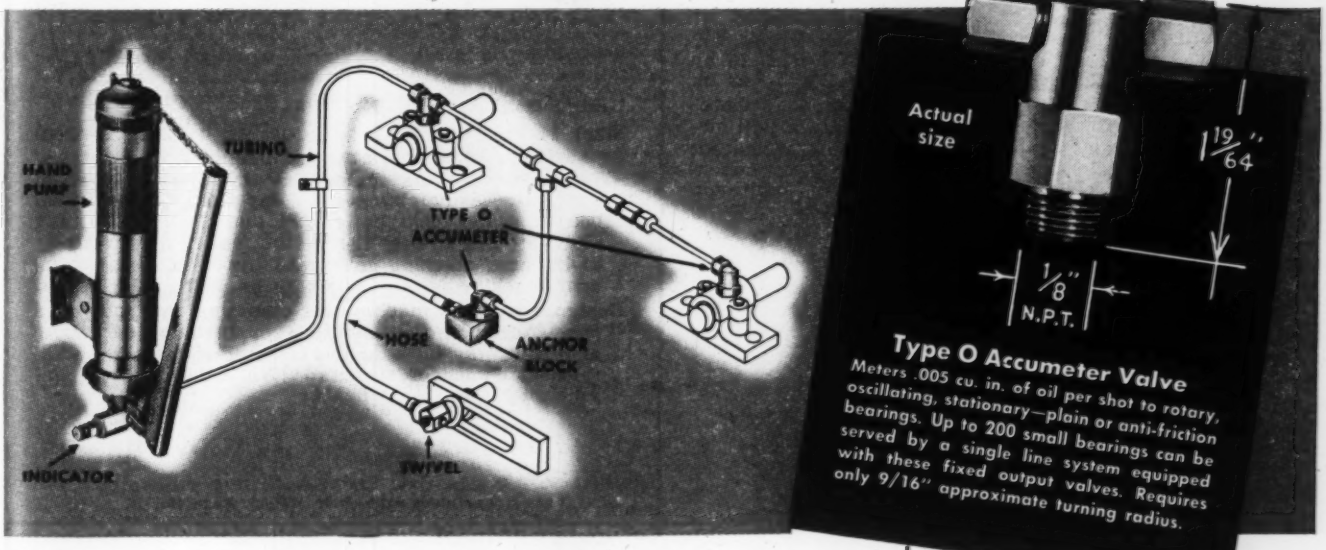
Design: Pulse transformer with core of special iron; impregnated and embedded in epoxy resin which will not support combustion; each lead numbered and color coded.

For more data circle MD-52, Page 209

ideal..., where close quarters make "ordinary" lubrication methods difficult...

ALEMITE Accumeter® CENTRALIZED LUBRICATION

lets you design low-cost, automatic lubrication into machines having many small bearings!



Type O Accumeter Valve
Meters .005 cu. in. of oil per shot to rotary, oscillating, stationary—plain or anti-friction bearings. Up to 200 small bearings can be served by a single line system equipped with these fixed output valves. Requires only 9/16" approximate turning radius.

Tiny, simple, accurate . . . Alemite Accumeter Type O Valves make it easy to design low-cost centralized lubrication into small machines, precision machines, *any* machine having many small bearings concentrated in limited space!

From One Central Point...in a fraction of the time required for hand lubrication . . . Accumeter Type O Systems deliver an exact, measured amount of fluid oil to *all* bearings—*while the machine is in operation!* No points missed . . . production time saved actually increases machine output. No wonder 95% of the big plants buying machine tools specify *centralized lubrication!*

Type O Accumeter System serves single machines or groups of machines—will handle any fluid oil. It is just one of three types of Accumeter Systems made by Alemite to meet your exacting requirements.

offers...
ALL THESE ADVANTAGES!

- Eliminates shutdown time for lubrication. *Adds* productive time to machine output.
- Seals completely against dirt, grit, water all the way from "Barrel-to-Bearing."
- Prevents bearing troubles due to neglect or use of wrong lubricant.
- Services *all* bearings—including those inaccessible or dangerous—in one operation.
- Avoids work spoilage and bearing repairs due to over-lubrication.

FACTORY-TESTED . . . FIELD-PROVED

Proved in the field. Exhaustive tests showed *no variation* in the amount of lubricant discharged . . . even after 73,312 lubrication cycles, *equal to 122 years of twice-a-day service.*

ALEMITE
REG. U. S. PAT. OFF.

A PRODUCT OF SW STEWART WARNER

Free—Alemite Accumeter Catalogue and Engineering Data Book.

ALEMITE, DEPT. R-23
1830 Diversey Parkway, Chicago 14, Ill.

Please send me my free copy of the Alemite Accumeter Catalogue and Engineering Data Book.

Name _____

Company _____

City _____ State _____

EQUIPMENT

REPRODUCTION CLOTH 53

. . . tracing cloth with emulsion coating

Peerless Photo Products Inc., Shoreham, Long Island, N. Y.

Reproductions can be contact printed on this cloth which may then be drawn upon.

Designation: Truflex.

Size: Rolls are 30, 36 or 42 in. wide and 10, 20 or 50 yards long; cut sheets 8½ by 11, 8½ by 12, 8½ by 14, 9 by 12, 11 by 17, 12 by 18, 17 by 22, 18 by 24, 22 by 34, 24 by 36, 30 by 42 and 36 by 42 in.

Service: Reproducing drawings by standard photographic process; after contact exposure usual developing, fixing, washing and drying are required; after drying cloth may be drawn on like conventional tracing cloth to make changes or additions; extremely durable, resists tearing and fraying highly transparent.

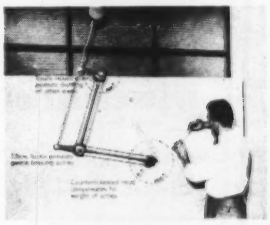
Design: Tracing cloth of long-staple, plastic-sized cotton coated with photographic emulsion; available in white or blue.

For more data circle MD-53, Page 209

DRAFTING MACHINE 55

. . . for drawing on vertical surfaces

V & E Mfg. Co., P.O. Box 950-M, Pasadena 20, Calif.



Machine simplifies production of large drawings.

Designation: No. 6100, No. 7100.

Size: 24 or 30 in. arms; for use with 12-in. vertical and 18-in. horizontal scales.

Service: For making engineering drawings on vertical surfaces; easily clamped to upper edge of vertical board; scales held horizontal and vertical or may be rotated in 15-deg increments; easily manipulated; 24-in. arm machine covers 36 by 60-in. area, 30-in. arm machine covers 42 by 84 or 48 by 72-in. area.

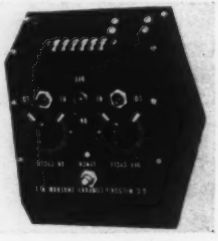
Design: Drafting machine for clamping to upper edge of vertical board; completely counterbalanced; brake at elbow may be adjusted from positive lock to full release; choice of standard (No. 6100) or civil engineering (No. 7100) heads.

For more data circle MD-55, Page 209

ELECTRONIC TIMER 54

. . . controls both on and off time

G. C. Wilson & Co., 2 N. Passaic Ave., Chatham, N. J.



This timer repeats the timing cycle until it is shut off.

Designation: Model No. 1.

Size: Cabinet measures 6 by 6 in.

Service: Controlling on and off time of electrically operated devices; cycle is continuous; on range is 0.2 to 200 seconds, off range is 0.1 to 60 seconds; operates on 105 to 120 v 60 cycle ac; controls 10 amp at 115 v ac noninductive or 2 amp at 460 v; highly stable and only slightly affected by line voltage and temperature changes.

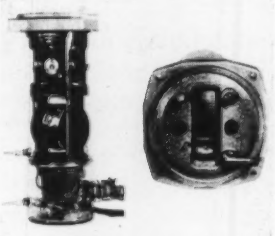
Design: Electronic timer; electron tube charges 2 resistance-capacitance networks to provide timing intervals; relay is double-pole, double-throw; all contacts wired to Jones plug or terminal strip; time intervals other than standard available; housed in steel cabinet with sloping front.

For more data circle MD-54, Page 209

PRESSURE METER 56

. . . is accurate to 1 part in 5000

Fischer & Porter Co., Hatboro, Pa.



This meter offers high accuracy and sensitivity, with compactness and portability.

Designation: Press-I-Cell.

Size: 5 in. diam, 14 in. long.

Service: Making accurate pressure measurements; typical pressure ranges are 1 atmosphere absolute, 400 in. water column and 150 in. of mercury differential; sensitivity of 1 part in 15,000; accuracy of 1 part in 5000; repeatability of 1 part in 7000; easily read; temperature-stable; unaffected by vibration.

Design: Pressure meter; has 50-ft scale on 35-mm film which is on sprockets; movement of scale manual or by servomotor; $\frac{1}{16}$-in. on scale is 0.0001 of full range; pressure sensing elements are precise metal capsules; for panel mounting.

For more data circle MD-56, Page 209

Prove to yourself...

These are better AN connectors--and at competitive prices

BETTER...

...Because Monowatt *AN* Connectors have *all* these features:

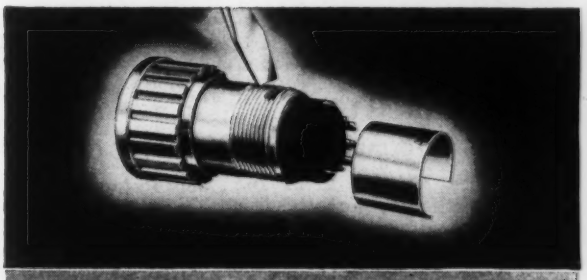
- ***Moisture-proof seal.*** **Two-piece inserts are joined with a silicone sealing compound. Moisture and condensation effectively excluded... parts held together while inserts are soldered to cable assemblies.**
- ***Diallyl Phthalate insert material*** **(blue) used in all connectors. Negligible post-mold shrinkage... superior dielectric properties.**
- ***Fewer parts and simpler design*** **make installation and inspection easy.**
- ***Cadmium-plated housings*** **resist corrosion.**
- ***Tellurium copper pins,*** **heavily silver-plated, insure greater conductivity... 99% that of copper.**
- ***Available in complete wiring harness or cable assemblies.*** **Made by Monowatt to your specifications.**

PRICED RIGHT...

...Because the Monowatt Department of General Electric has complete modern facilities for mass-production, these features are offered at competitive prices.

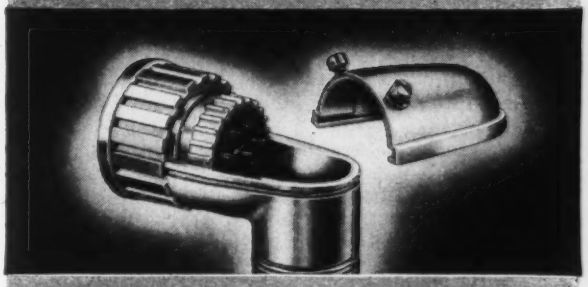
THE PROOF STARTS WITH THE QUOTATION

...*Prove to yourself* that Monowatt *AN* Connectors at competitive prices bring you extras—extras which save assembly time and insure a superior connecting job.



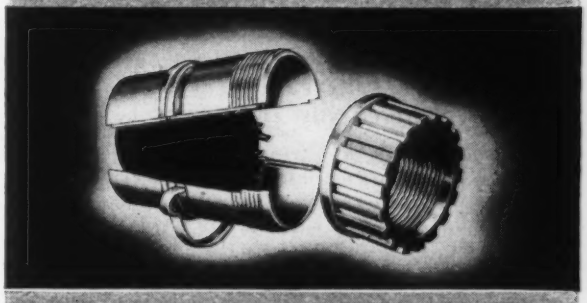
AN Solid Shell Connector

BETTER... because its snap-in retaining sleeve cannot work loose, yet can be released quickly with a screw driver and the insert removed for inspection or soldering.



AN Split-Shell 90° Angle Plug

BETTER... because top can be removed to inspect wiring without unmating or disassembling plug from conduit or cable. Conduit thread is not split. Split-shell ease of wiring is combined with advantages of solid shell construction.



AN Split-Shell Straight Plug

BETTER... because Monowatt engineers have succeeded in reducing number of metal parts and weight, while improving connector performance. This type is preferred where assembly must be made in tight places.

Send your specifications with this coupon. In return you'll receive a catalog describing the unique cost-saving features of Monowatt electrical connectors and wiring assemblies for aircraft, ordnance and electronic equipment — plus — quotations on your specific requirements. If you wish, a representative will call with sample connectors... all without cost or obligation.

MAIL COUPON AND YOUR SPECIFICATIONS TODAY.

MONOWATT

Monowatt Department A-2, General Electric Company
95 Hathaway St., Providence 7, R. I.

☐ Please quote on the attached specifications and send catalog.
☐ Please quote on the attached specifications and have your representative call with sample connectors.
☐ Please send catalog only.

I understand neither the quotation, catalog nor call obligates me in any way.

Name .....
Title .....
Firm .....
Street ..... Zone ..... State .....
City .....

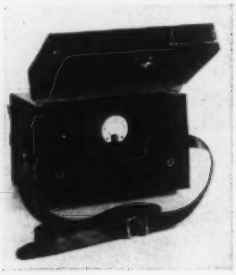
A DEPARTMENT OF GENERAL ELECTRIC COMPANY, PROVIDENCE 7, R. I.

EQUIPMENT

SOUND ANALYZER 57

. . . determines noise frequency and intensity

Herman Hosmer Scott Inc., 385 *Putnam Ave., Cambridge* 39, *Mass.*



Noise, sound and vibration studies are facilitated by this instrument.

Designation: Type 420-A.

Size: 10 by 10 by 6 in.; weighs 20 lb.

Service: Determining intensity of sounds of various frequencies; range up to 20,000 cycles per second.

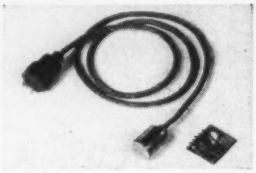
Design: Sound analyzer; consists of variable-width band-pass filter, calibrated attenuator and intensity meter; pass band width is adjustable in steps of ½ octave; position of pass-band in audio frequency range is adjustable; housed in saddle leather case with shoulder strap, allowing operator to use instrument while walking about; output jack permits use as filter; may also be used as audio frequency amplifier.

For more data circle MD-57, Page 209

PRESSURE TRANSDUCER 58

. . . weighs only 20 grams

Consolidated Engineering Mfg. Corp., 300 *N. Sierra Madre Villa, Pasadena* 8, *Calif.*



Flush diaphragm type construction assures that there will be no spurious turbulence due to the pick-up itself.

Designation: Type 4-310.

Size: ½-in. diam, ¾-in. long; pickup alone weighs 20 grams; 35 grams complete with cable.

Service: Varying voltage proportional to pressure changes; pressure ranges of zero to 0.5, 15, 50 or 150 psi available; usable at temperatures of −65 to 165 F; will withstand 300 per cent overload without damage; excitation 10 v dc or ac at 5000 cycles maximum; input and output impedances are 350 ohm; linearity better than 1 per cent of full scale output; response to static acceleration is 0.05 per cent of full scale per *g*, to vibratory acceleration less than 0.2 per cent of full scale per *g* to 2000 cycles.

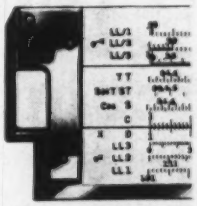
Design: Pressure transducer; variation of pressure on diaphragm causes change in resistance of two active arms of four-arm bridge to vary output voltage; output may be used to drive galvanometer or amplified and applied to other meter or oscilloscope.

For more data circle MD-58, Page 209

SLIDE RULE 59

. . . is color coded to simplify calculations

Frederick Post Co., Dept. V, 3650 *Avondale Ave., Chicago* 18, *Ill.*



Scales of trigonometric functions have the same color as the corresponding C, D or CI scales.

Designation: Versalog.

Size: 10 in. long scales.

Service: Performing engineering calculations; color coding eliminates possible confusion; all reciprocal scales are in red; accuracy unaffected by atmospheric conditions.

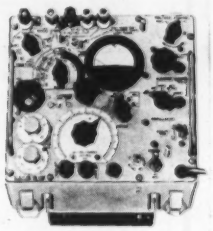
Design: Slide rule; laminated construction; conventional A and B scales are replaced by R_1 and R_2 scales which are folded 20 in. scales; C and D scales appear on both sides of slide rule; also has scales CF, DF, CI, CIF, K, L, LLO, LL1, LL2, LL3, LL/0, LL/1, LL/2, LL/3, T, Sec T, ST and Cos S; comes in leather case and with 120-page clothbound instruction manual.

For more data circle MD-59, Page 209

IMPEDANCE BRIDGE 60

. . . measures resistance and reactance

Clough-Brengle Co., 6014 *Broadway, Chicago* 40, *Ill.*



Good accuracy, small size and lightweight are combined in this instrument.

Designation: Model 712.

Size: 5½ in. high, 8⅞ in. long, 8⅜ in. wide; weighs 14 lb.

Service: Measuring capacitance, inductance and resistance; also measures transformer turns ratio, capacitor leakage current, dissipation factor, D, and storage factor, Q; tests capacitors for open and short circuits; capacitor range from 10 mmfd to 100 mfd, accuracy is ±2 per cent from 10 mmfd to 100 mfd, ± 5 per cent from 100 to 1100 mfd; measures inductance from 100 microhenries to 110 henries; accuracy is ±2 per cent from 100 microhenries to 1 henry, ±3 per cent from 1 to 110 henries; measures resistance from 1 ohm to 11×10^6 ohm, accuracy ±2 per cent.

Design: Impedance bridge; contains 1000 cycle per second oscillator for making capacitance and inductance tests.

For more data circle MD-60, Page 209

Advertisement

Custom-Built Hoists Cut Materials Handling Costs

By designing each hoist to meet not only current materials handling problems but also with a view to projected plant expansions by the customer, Reading Crane & Hoist Corporation is able to make installations that permit substantial economies in materials handling costs under both present and future conditions.

This Reading Electric Hoist, equipped with a Star-Kimble Brakemotor requires only 3 men for the handling of steel bars—a job on which 6 men were formerly needed.

In line with its policy of building the best of components into its specially engineered hoists, Reading has been a consistent user of Star-Kimble Brakemotors, which are used on both trolley and hoist. In some instances, Star-Kimble Right-angle Gearmotors are used on trolley and hoist.

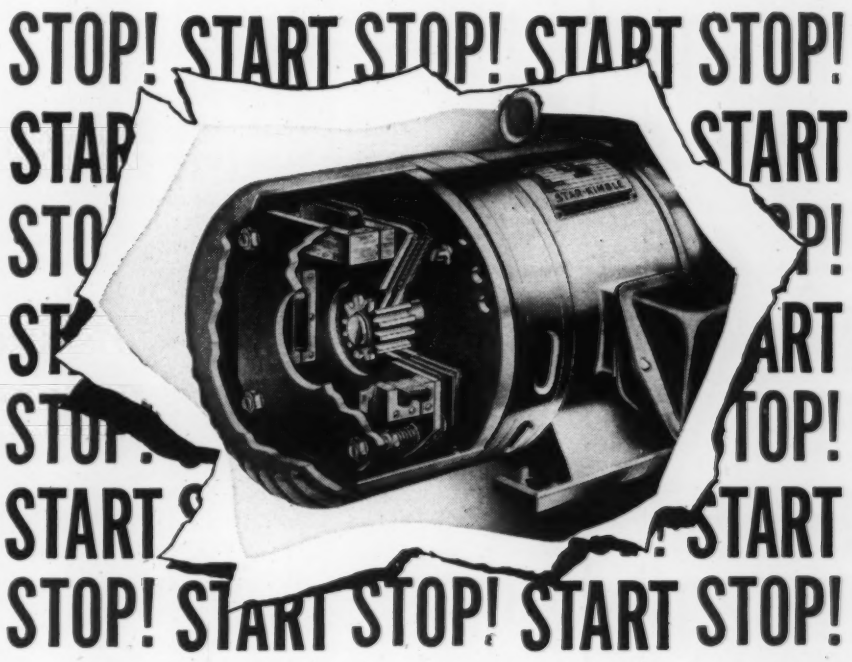
User for 30 Years

Reading has been a customer of Star-Kimble's for more than 30 years, purchasing sizes from 1 to 25 hp. These compact assemblies of a motor and a brake, engineered to work together and built together in a single unit are "of fine quality and give splendid service," according to Reading.

Detailed information on construction details, motor capacities and torque ratings of these Brakemotors is contained in Bulletin B-501-A, which is available on request from the manufacturer, Star-Kimble Motor Division of Miehle Printing Press and Mfg. Co., 201 Bloomfield Avenue, Bloomfield, N. J.

Positive, split-second stopping

SMOOTH, NO-DRAG STARTING
FAST, NON-PLUGGING REVERSING



You get them all when you specify Star-Kimble Brakemotors

NOTE THE EXTRA-LARGE BRAKELINING AREA—discs machined on both sides to give full, positive contact—that brings a Star-Kimble Brakemotor *and its connected load* to the same sure fraction-of-a-second stop through *millions of operations.*

NOTE THE SMALL AIR GAP between electromagnets and brake armature disc. It assures quick brake release—allows the load to start freely when the motor is energized.

COMPARE THE REVERSING CYCLE of a Star-Kimble Brakemotor and a motor reversed by conventional plugging. Typical figures on maximum starts per minute for a 5 hp motor: with plug stops, *three;* with the Star-Kimble way, *ten!*

REMEMBER a Star-Kimble Brakemotor is a compact, integral unit, with a short sturdy shaft that's common to motor and brake. Saves space—saves bearing and brakelining wear. *One* manufacturer—*one*-responsibility.

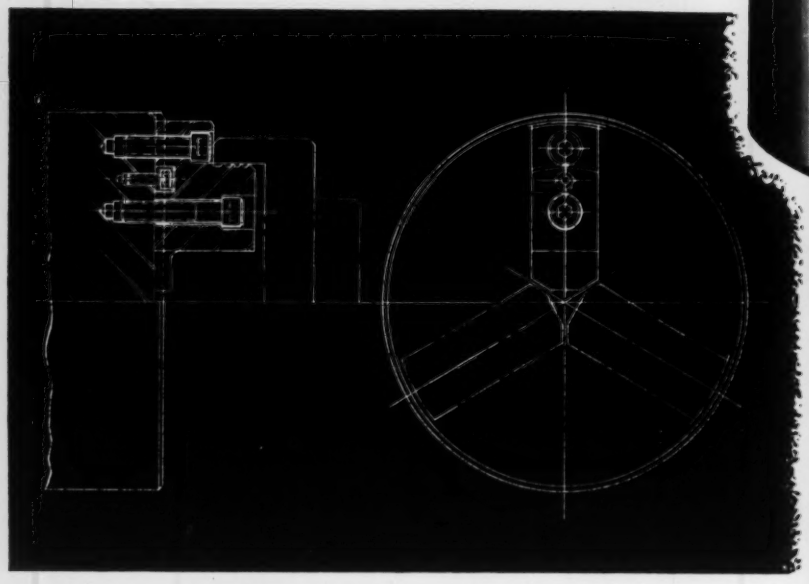
For information on design and service features, write for Bulletin B-501-A

STAR-KIMBLE
MOTOR DIVISION OF
MIEHLE PRINTING PRESS AND MFG. CO.
201 Bloomfield Avenue Bloomfield, New Jersey

SPECIFY HOLO-KROME

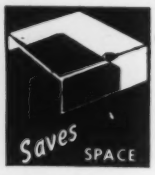
the BETTER fastening method.

CAP SCREWS



Socket Head CAP SCREW

H-K INTERNAL WRENCHING



Guaranteed Unfailing Performance

CALL YOUR H-K AUTHORIZED INDUSTRIAL DISTRIBUTOR TODAY

HOLO-KROME

Completely Cold Forged

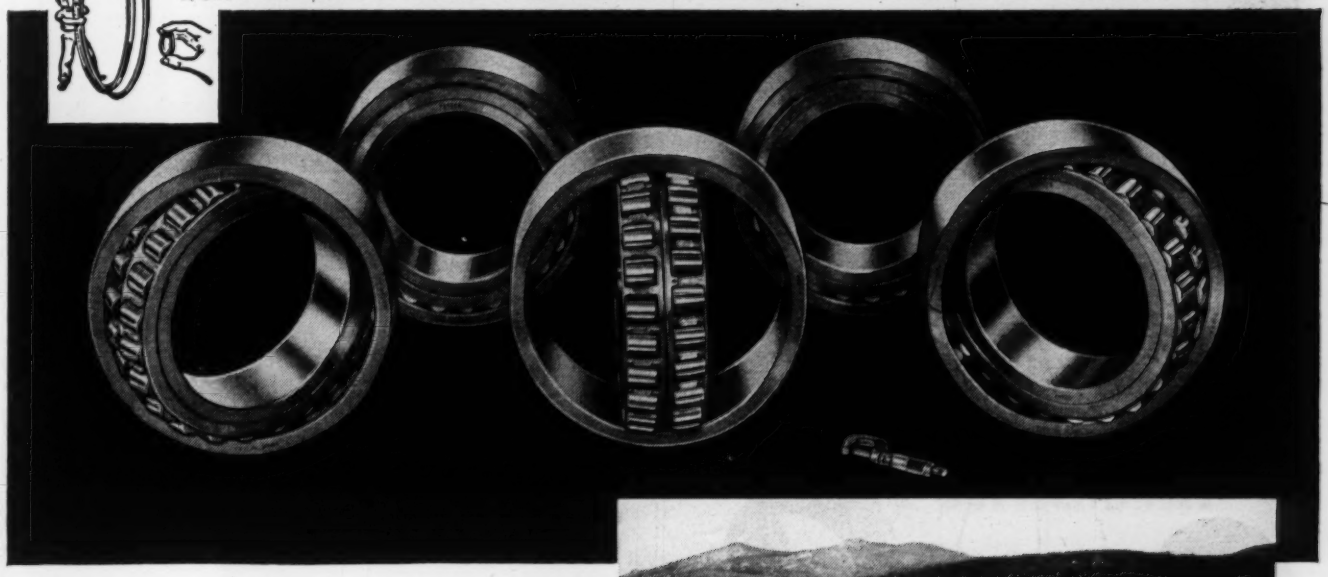
SOCKET SCREWS

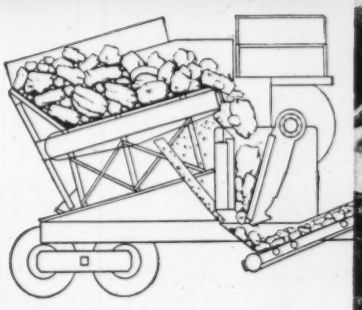
D7

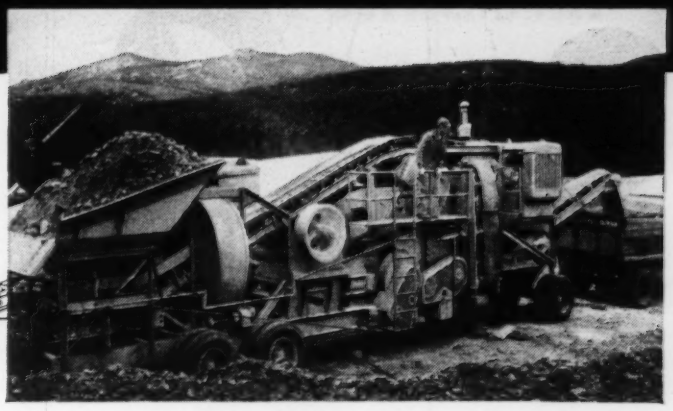
THE HOLO-KROME SCREW CORP., HARTFORD 10, CONN. U. S. A.

Contact KAYDON of Muskegon

FOR ALL TYPES OF BALL AND ROLLER BEARINGS: 4" BORE TO 120" OUTSIDE DIAMETER







KAYDON-bearinged Cedarapids Jaw-Crushers are dependable!

Spherical, self-aligning, anti-friction bearings, 8.6614" x 13.3858" x 3.5433", with one-piece bronze cage, as used in jaw crusher of this Cedarapids Junior Tandem Portable Crushing Plant, made by Iowa Mfg. Co., Cedar Rapids, Iowa. Other sizes of KAYDON Bearings, 12.5984" to 14.9606" Outside Diameter, are used on various models.

ROCK crushing that used to be a slow, tedious, costly, "man-killing" job is made simple and profitable with famous Cedarapids portable crushing plants. Husky KAYDON precision bearings help the jaw crusher of this multi-ton machine operate smoothly and efficiently in crushing up to 75 to 135 tons of rock per hour into gravel sized 1-inch or less. • These rugged bearings help deliver maximum crushing power, assure smoother operation, reduce maintenance, and thus help improve production and profits.

On many types of heavy-duty industrial machinery and war equipment, big KAYDON bearings are making tough jobs easier, more profitable, with dependable, controlled precision. Machine designers welcome KAYDON bearing versatility. Frequently the adoption of these bearings leads to new horizons in bigger, better machinery for unusual quality-and-cost-control in modern production.

We'll be glad to work with you on difficult bearing problems.

KAYDON Types of Standard and Special Bearings:
Spherical Roller • Taper Roller • Ball Radial • Ball Thrust • Roller Radial • Roller Thrust • Bi-Angular Bearings

THE KAYDON ENGINEERING CORP.

MUSKEGON • MICHIGAN

PRECISION BALL AND ROLLER BEARINGS

Purebon

SOLVES MANY PROBLEMS
caused by sliding or rotating parts which are DIFFICULT OR IMPOSSIBLE TO LUBRICATE

A constantly increasing stream of problems are facing engineers and designers today involving sliding or rotating parts where lubrication is difficult or impossible. For such applications, Purebon, the mechanical carbon, is often the ideal answer. Typical applications are seal rings, bearings, pistons, piston rings, pump vanes, valve seats, meter discs, and a host of similar items. Purebon comes in a wide variety of grades. It is strong, tough, readily machinable and in many cases can be molded directly to size.

Bulletin No. 52 tells the complete story of Purebon.
Write for your copy today.

PURE CARBON CO., INC.
446 HALL AVE. **ST. MARYS, PA.**

MEN OF MACHINES

Robert Cass

Assistant to the president of The White Motor Co., Cleveland, **Robert Cass** has been elected president of the Society of Automotive Engineers for 1953. He has begun a speaking and inspection tour which will take him all over the country and to Hawaii and Canada.

Mr. Cass, who was born and educated in England, spent some time in the Royal Naval Air Service during World War I. After the war he joined Short Brothers Aircraft Co. in England. He came to this country in 1924 as an instructor in engineering at Harvard University and a year later joined the White engineering department. He was promoted to chief engineer and was named assistant to the president in 1945. For the past 18 months he has been on loan to the National Production Authority, which he will continue to serve as a consultant. Mr. Cass was chairman of the Cleveland Section of SAE in 1947-1948.

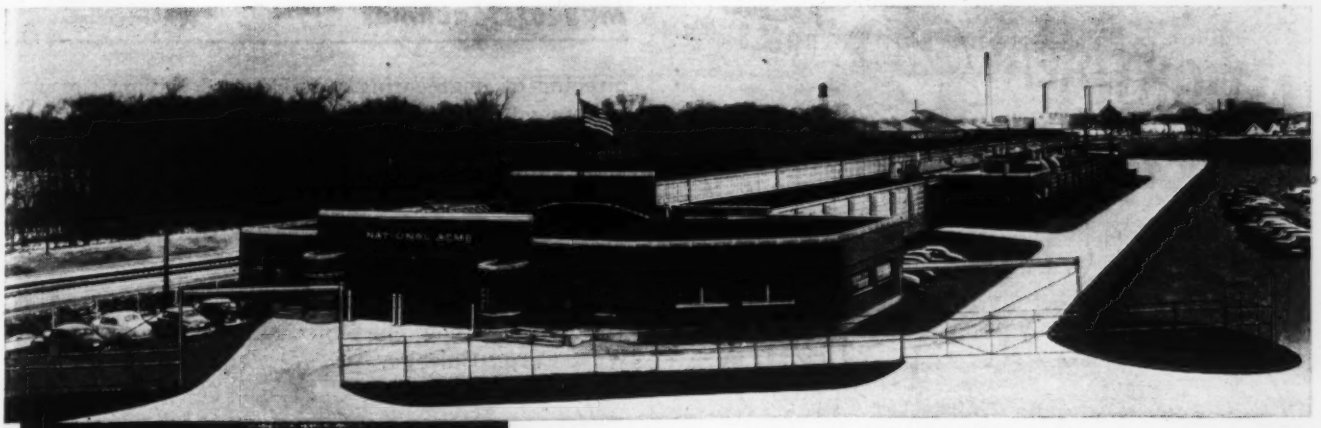
♦

To direct the design and production of various electrical and electronic products, including a new line of magnetic amplifiers, **David H. Ransom** has been appointed chief engineer of the Electronic Div. of Karl-Douglas Associates, Hawthorne, Calif. He was formerly director of research at Bogue Electric Mfg. Co.

♦

R. J. S. Pigott, who recently completed his term as president of the American Society of Mechanical Engineers, has retired from the position of director of engineering of Gulf Research & Development Co., Pittsburgh. He will continue in the capacity of consultant to the company he has served for 23 years.

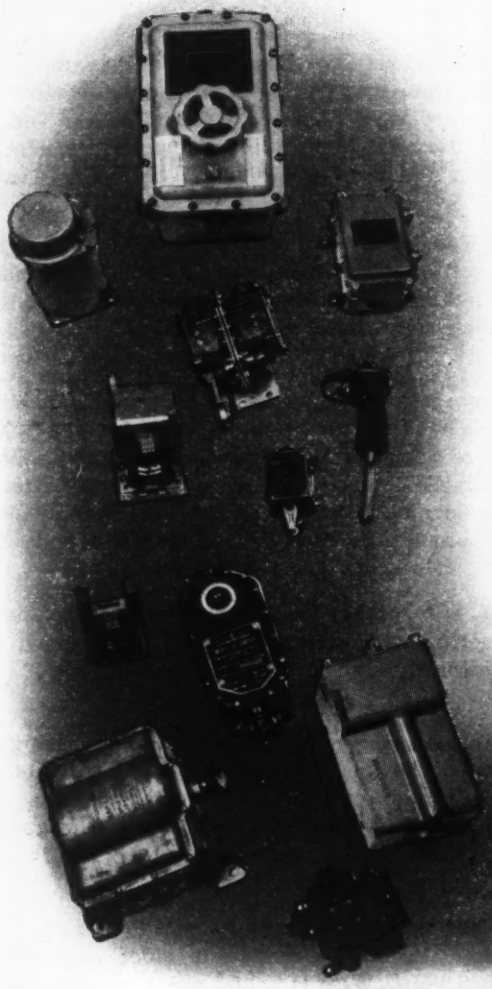
Concurrently, the Engineering division of the company was divided to form an Engineering and an Automotive Engineering division. **E. Topanelian Jr.,** formerly assistant director of the Engineering Div., has been appointed director of engineering, and **Bruce R. Walsh,** formerly head of the industrial engineering section of the Engineering Div., is now assistant



better Solenoids and Switches...

because our own engineers

were **HARD TO PLEASE**



We started manufacturing Namco "Stellite"-Welded Solenoids and Snap-Lock Switches because of the high degree of ruggedness and dependability our own engineers demanded in the electrical and hydraulic circuits of our Acme-Gridley automatic machines. These devices have since been adopted as standard equipment by 85% of other large machine tool manufacturers.

Of almost equal importance to most of our customers is the vast specialized engineering experience available to them from National Acme—to help determine correct capacities, housings, space, type of mountings, and to assist with special problems—thus to insure the most practical applications at the lowest cost.

For example, here is just one group of switch and solenoid devices supplied to the Army, Navy and Aircraft services wherein *there is no room for failures.* These include:

Water-resistant, highly sensitive units for submarines.

High shock-resistant assemblies for synchronizing multiple gun fire, ashore and afloat.

Remote control switches for pin-pointing aircraft fire.

Air Conditioning and Refrigeration master controls—and many others.

Catalogs of Namco Switches (EM-51) and Solenoids (EM-52) explain the patented advantages of these lines. Ask for them or better still, if you have a problem, ask your engineers to consult ours.

ELECTRICAL MANUFACTURING DIVISION

The NATIONAL ACME CO.

180 East 131st Street • Cleveland 8, Ohio

ACME-GRIDLEY BAR AND CHUCKING AUTOMATICS, 1-4-6 AND 8-SPINDLE—HYDRAULIC THREAD ROLLING MACHINES—AUTOMATIC THREADING DIES AND TAPS—LIMIT, MOTOR STARTER AND CONTROL STATION SWITCHES—SOLENOIDS—CONTRACT MANUFACTURING

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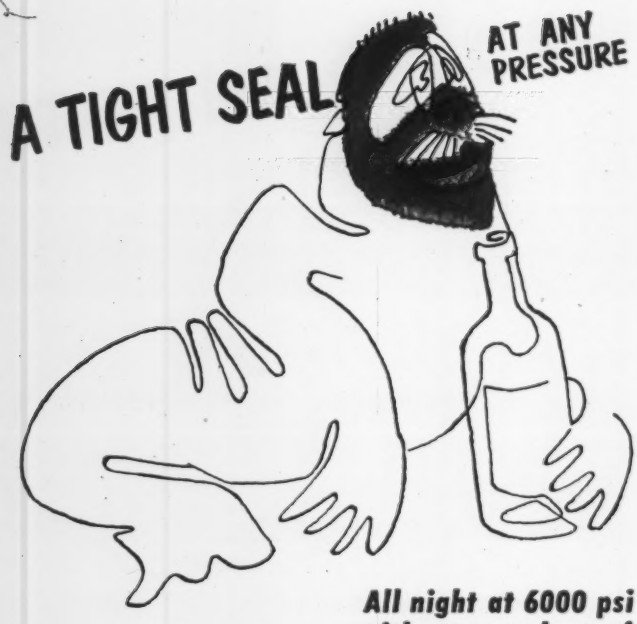

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Low Handle Load
Not Critical to Dirt
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High Flow Capacity
Low Maintenance

MANUAL VALVES

Vacuum to 6000 psi

pipe sizes to 1 ½ inch

. . . come in the following flow patterns: Shut-off, Manipulator, Four-Way Selector, and Dual Pressure Selector.

For complete technical information see our catalog in Sweet's 1953 File for Product Designers and in the Plant Engineer's File, or write for Catalog 2B-S on Manual Valves and Catalog 1B-2 on Solenoid Valves.

BARKSDALE VALVES

1566 E. SLAUSON AVE., LOS ANGELES 11, CALIF.

Men of Machines

director of engineering. **J. Edward Taylor,** formerly a member of the product development and product engineering department of the Gulf companies, has been transferred to the Research department as director of automotive engineering; **Charles R. Butler** and **R. L. Kirkpatrick** are his assistants.

♦

Formerly chief production engineer, **Edward O. Marquardt** is now chief mechanical engineer of Taco West Corp., Chicago.

♦

Samuel H. Wood has been appointed manager of the Marion Forge Div. plant of Eaton Mfg. Co., now under construction at Marion, O. Mr. Wood joins Eaton after 18 years as chief engineer of the Forge Div. of Timken-Detroit Axle Co. He was previously associated with the Packard Motor Co. as assistant chief engineer in charge of tool design, and with Ford Motor Co.

♦

C. Harvey Pecor has been appointed manufacturing engineer of the hydraulic control division of Blackhawk Mfg. Co., Milwaukee.

♦

Flexitallic Gasket Co., Camden, N. J., has appointed **A. T. Erickson** as executive vice president. He was formerly associated with Day & Zimmermann Inc., in such capacities as chief estimator, superintendent of construction and project engineer.

♦

Victor Tanski, whose entire business career has been concerned with plant layout, machine design and engineering operations, has been appointed general manager of Replac Corp., Cleveland.

♦

New associate works manager for the Penn Metal Co. Inc., New York and Boston, **Jack O. Abney** will have charge of research and development at the firm's Parkersburg, W. Va., plant. He was formerly director of standards and methods engineering for the Chevrolet Div. of General Motors Co. in Indianapolis.

♦

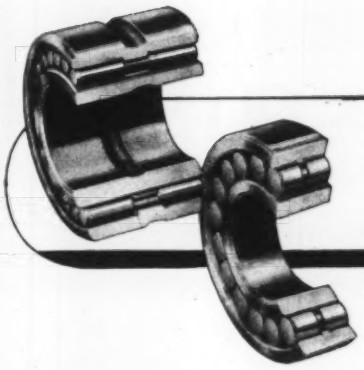
Louis J. Sarosday has been appointed vice president of engineering of J. B. Beaird Co., Shreveport, La. He was formerly associated with Blaw-Knox Co.

♦

New director of commercial product engineering for the Ternstedt Div. of General Motors Corp., Detroit, **Frank O. Riley** succeeds **A. J. DeSana,** who has been named engineering executive assistant to the general manager of the division.

♦

Floyd A. Garman has been appointed chief engineer, and **Walter V. Magee,** assistant chief engineer of American Steel & Wire Div. of U. S. Steel Co., Cleveland. Mr. Garman succeeds **Harry L. Jenter,** who was promoted to the position of assistant manager of operations of the Cleveland district.



Over 33% Greater Capacity For The Same Size

There is a challenge facing manufacturers today to build smaller and more compact machines with extra precision and to combine more operations in each machine. This makes the selection of the proper bearings extremely important. A definite plus factor in this selection is the availability of a precision bearing that will deliver extra load carrying capacity in a minimum amount of space.

Obviously roller bearings, and particularly those of the small (needle) roller type occupy far less bearing space for equivalent capacity than ball bearings. Roller bearing capacity is built up in proportion to the effective race and roller contact provided. Thus a full type roller bearing *without space wasting cages* should provide the greatest capacity of any type of anti-friction bearing. However, to offer a perfect bearing the resulting full roller complement must be prevented from skewing and binding where misalignment occurs in the application.

The Guiderol bearing is the accepted answer to all these requirements considering precision, load capacity,

Bearing	McGill Guiderol No. GRI-209	Brand A Bearing	Brand B Bearing	Brand C Bearing	Brand D Bearing
Published Load Rating	8370 lbs.	6700 lbs.	7000 lbs.	5520 lbs.	6080 lbs.

Capacities at 2500 hours average life at 100 RPM

long life, versatility of mounting, and ease of lubrication. Published ratings show the Guiderol CT Series bearing has over 33% greater load carrying capacity than the average of the four highest rated interchangeable bearings. As a result, a Guiderol bearing at least one size smaller can often be substituted with the necessary shaft and housing requirements reduced in size and cost.

How Rollers Are Guided

In the Guiderol bearing design the grooved rollers with full race width contact are prevented from skewing by a center guide rail. Normally the rollers run on a true axis

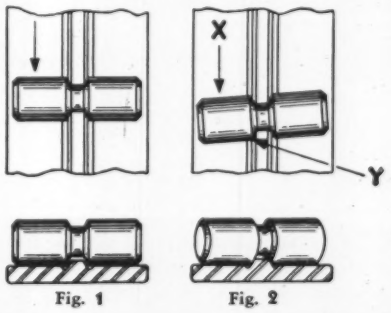
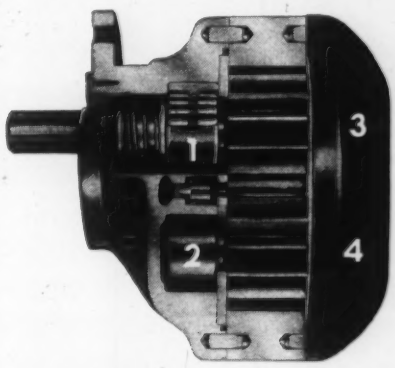


Fig. 1 Fig. 2

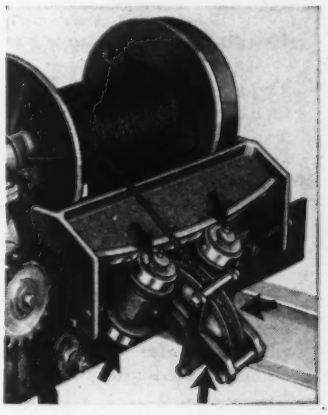
— not contacting the rail and thus need no correcting. (Fig. 1) Should misalignment cause a shift off center (Fig. 2) the leading end of the roller is retarded by contact with the rail at location Y. The trailing end catches up, relieving the rail contact, and the roller then resumes normal operation.

Typical GUIDEROL® Bearing Mountings

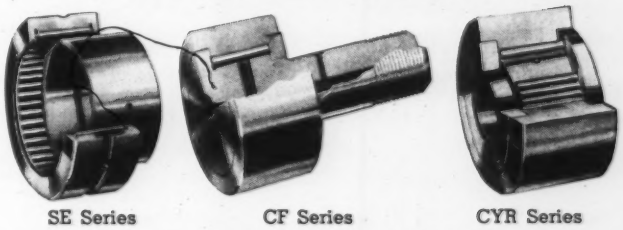


On a Hydreco Gear Pump Idler and Drive Shaft, 4 Guiderol bearings are used. The longer rollers of the Guiderol bearings are effective virtually to the edge of the races. This gives substantial support close to the gear and materially reduces shaft deflection.

Four Guiderol bearings support and guide an automatic spooling attachment across the face of the reel track on a 20,000 pound Gar Wood Reel-Lite Winch. The guided roller principle prevents skewing of rollers in the 4 vertically mounted bearings even with a 10,000 pound angular load per bearing. A fifth Guiderol bearing in the sheave provides added stability and eliminates binding due to off-center loading.



MULTIROL® Bearings



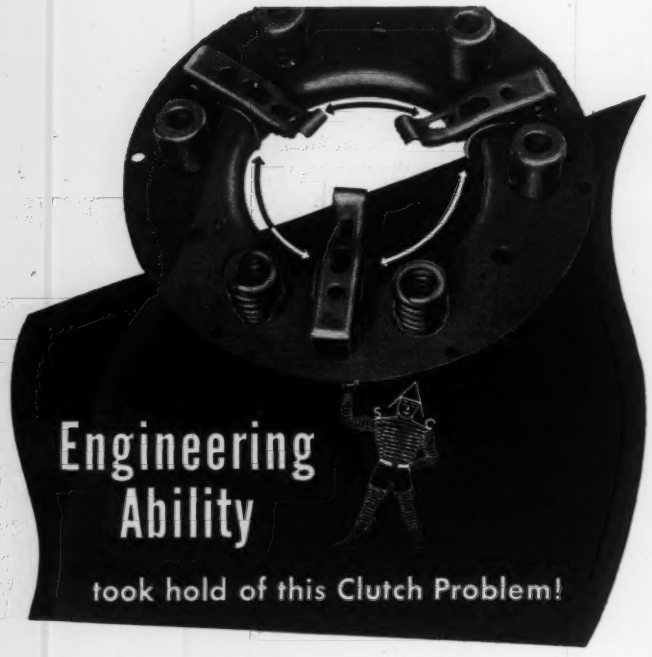
SE Series CF Series CYR Series

A new 140-page Bearing Reference Guide complete with 30 pages of vital engineering data has just been released by the McGill Manufacturing Company.

It has the full story on the advantages of Guiderol Bearings and in addition contains complete information on the well-known Multirol CF, CYR and SE Bearings. *Send now for your copy of the McGill Catalog No. 52.*

McGILL® — Precision Bearings

McGILL MANUFACTURING COMPANY, INC.
200 N. Lafayette Street, Valparaiso, Indiana



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AUTOMATIC SPRING COILING COMPANY

This clutch manufacturer was having a problem.

The action of a lever in this particular type of clutch was such . . . that tension had to be applied in quite an unusual manner. And not only was there no standard spring to do the job . . . but also no known machine capable of turning out the necessary custom-built spring!

Then Automatic Spring Coiling Co. was called in . . . and we put *Engineering Ability* to work.

Our consulting engineers analyzed the situation . . . and designed a *special machine* to produce a special *spring* . . . which was also **Shot-peened* for fatigue strength, thereby adding immeasurably to its life potential.

Samples were made and put to repeated and conclusive tests. RESULT: More perfect clutch operation with guaranteed longer life and a considerably lessened chance for shock, slippage, vibration, grabbing and chattering.

Make it a point to consult Automatic Spring Coiling Company early in the job. Take advantage of our . . . ENGINEERING ABILITY . . . gleaned from 30 years of Precision mechanical spring specialization, and by strict adherence to Quality-Controlled standards.

**Incidentally*, "Shot-peened" *springs for added fatigue strength are among our specialties.*

Our veteran consulting engineers are ready to survey your requirements without obligation. Write us today for full details.

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THE ENGINEER'S Library

Recent Books

Investment Castings for Engineers. *By Rawson L. Wood and Davidlee Von Ludwig; 487 pages, 6 by 9 inches, clothbound; published by Reinhold Publishing Corp., New York; available from* MACHINE DESIGN, *$10.00 postpaid.*

A modern counterpart of the ancient artisan's "lost wax" process, investment casting has only seen industrial application as a precision casting technique for a little more than ten years. It offers advantages in the intricacy and tolerances attainable as well as in the variety of alloys which may be cast. The intention of this book is to define clearly what can be accomplished by the various commercially important variations of the process currently in use. Emphasis is placed on the basic principles which have proven essential to the design, production and application of successful investment precision castings. An introductory chapter deals with the history and description of the process and is followed by chapters covering casting techniques, metal selection, finishing operations, product development, application case histories, design suggestions and metallurgical considerations. The concluding portion of the text is devoted to a bibliography.

♦

Engineers' Illustrated Thesaurus. *By Herbert Herkimer, 588 pages, 5½ by 8 inches, clothbound; published by Chemical Publishing Co. Inc., New York; available from* MACHINE DESIGN, *$6.00 postpaid.*

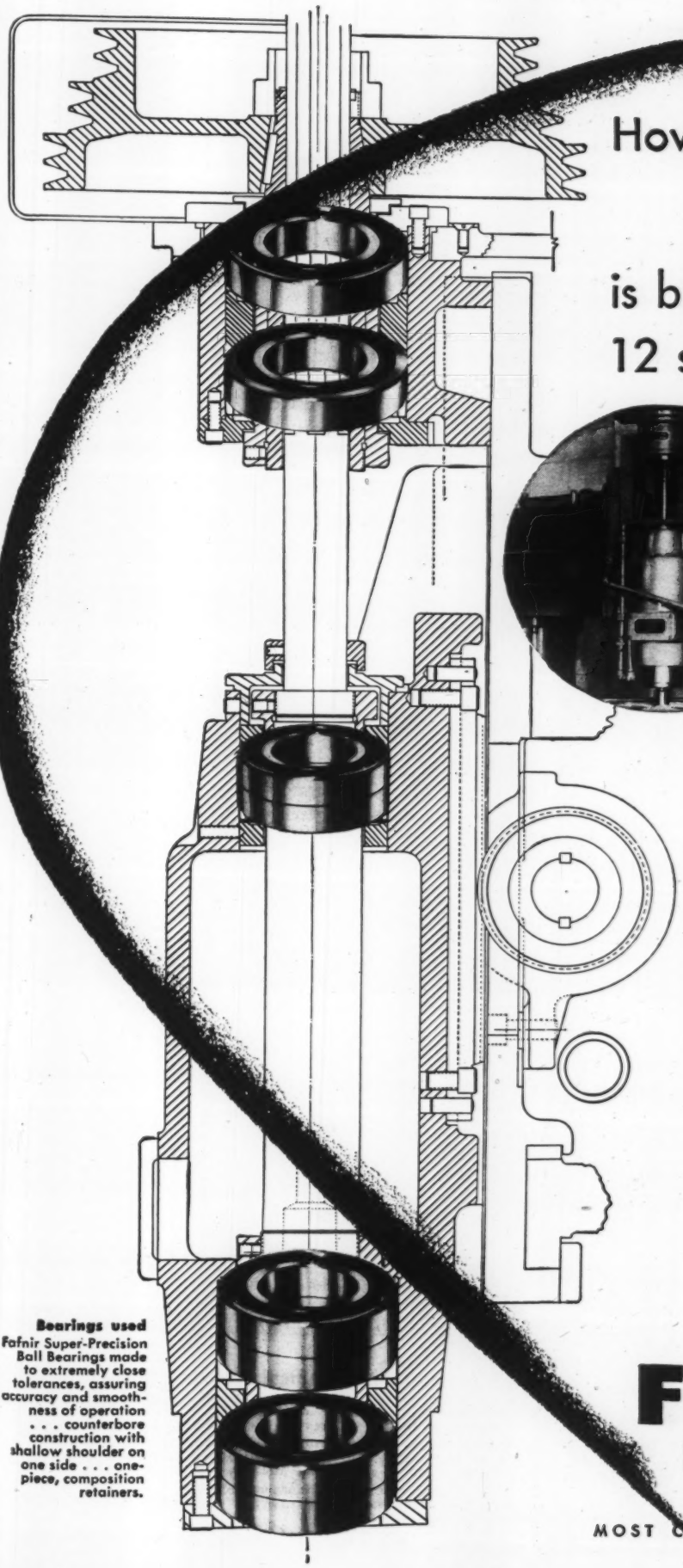
Over 8000 thumbnail sketches of machine components and structures pertaining to mechanical engineering and other fields make up the contents of this reference manual. Material has been selected from the author's scrapbook collection, accumulated over a period of more than thirty years, of engineering drawings, sketches, diagrams and abstracts from various domestic and foreign patent-office gazettes and trade catalogs. Descriptive information has been kept to minimum and illustrations have been arranged and indexed for rapid referencing.

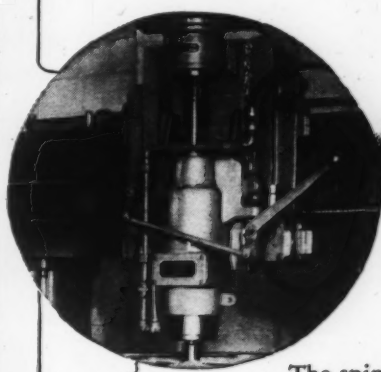
♦

Electron Tubes in Industry. *By Keith Henney, editor, and James D. Fahnestock, associate editor, Electronics; 363 pages, 6 by 9 inches, clothbound; published by McGraw-Hill Book Co. Inc., New York; available from* MACHINE DESIGN, *$6.00 postpaid.*

Designed as a manual on industrial electron tube usage, this third edition has been completely rewritten to bring all parts up to date and eliminate un-

How "ABUSE CAPACITY" is built into a 12 speed spindle





The spindle of Pratt & Whitney's 40" Vertical Profiler and Miller is designed for 12 operating speed ranges from 260 to 6200 r.p.m. Machine operations may be confined to continuous production at any one speed for extended periods. The diversification of operating conditions represented puts an extremely heavy burden on spindle bearings.

"Abuse capacity" is provided by the aristocrats of all bearings . . . Fafnir Super-Precision ball bearings. Four pairs support the main spindle and drive shaft. Notice how they are arranged in the cross section diagram. This set-up not only assures positive axial and radial rigidity, but also provides for shaft expansion. The bearings run cool under varying conditions of load and speed . . . conserve power . . . need no adjustment . . . and are permanently grease packed.

Whatever your bearing problem, a few minutes spent with a Fafnir representative may help you solve it as successfully. The Fafnir Bearing Company, New Britain, Conn.

Bearings used
Fafnir Super-Precision Ball Bearings made to extremely close tolerances, assuring accuracy and smoothness of operation . . . counterbore construction with shallow shoulder on one side . . . one-piece, composition retainers.

FAFNIR
BALL BEARINGS

MOST COMPLETE LINE IN AMERICA

Smooth...
Power
Transmission

LOVEJOY
FLEXIBLE COUPLINGS

MODERN DESIGNers specify *Lovejoy Flexible Couplings* because they offer the best obtainable insurance against alignment troubles—dampen and absorb starting torque, vibration and shock of intermittent loads . . . protect motor and driven machine . . . lengthen bearing life. *Lovejoy Flexible Couplings* are rugged in construction, provide excellent resiliency. Bodies are carefully machined. Cushions are available in materials suited to the particular load conditions . . . can be changed without shutdown. No lubrication is needed.

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Engineer's Library

necessary material. Theoretical aspects of tube technology have been kept to a minimum in the text; however, detailed references to advanced information are provided. In illustrating fundamental application techniques, the authors present a wide variety of typical circuits, many of which have found successful application in industry.

Text material is introduced by a chapter discussing basic circuit elements. Fundamentals of electron tubes are taken up next followed by a chapter on basic tube circuits. Succeeding chapters cover rectifiers and power supplies; light-sensitive tubes; thyratron tube circuits; relays and relay circuits; electronic motor control; electronic measurement and control; counters and divider circuits; and high-frequency heating and welding.

Association Publications

How to Improve the Utilization of Engineering Manpower. 55 *pages,* 6 *by* 9 *inches, stiff-paper bound; copies available from National Society of Professional Engineers,* 1121 *Fifteenth St. N.W., Washington* 5, *D. C.;* $2.00.

Second of a series, this report summarizes an Executive Research Survey sponsored by the National Society of Professional Engineers through its Professional Engineers Conference Board for Industry. The study is intended to help industry use its engineers more effectively. More than 459 companies employing engineers were polled on the subject of manpower utilization. The first seven chapters of the report are concerned with the interpretation of survey results and information is presented on indoctrination of engineers, making the existing engineering staff more effective, use of supporting personnel, misuse of engineering talents, auxiliary sources of engineering talent, causes and results of engineering turnover, and preparing the engineers of the future. In the concluding chapter, survey results are summarized and recommendations are offered as to how companies may better utilize their engineering personnel.

Government Publications

NACA Technical Series. *Each publication is* 8 *by* 10½ *inches, paperbound, side-stapled; copies available from National Advisory Committee for Aeronautics,* 1924 *F St. N.W., Washington* 25, *D. C.*

The following Technical Notes are available:

2799. **Simple Graphical Solution of Heat Transfer and Evaporation from Surface Heated to Prevent Icing**—19 pages.

2802. **Bonding of Molybdenum Disulfide to Various Materials to Form a Solid Lubricating Film. II—Friction and Endurance Characteristics of Films Bonded by Practical Methods**—16 pages.

2803. **A Theoretical and Experimental Investigation of the Influence of Temperature Gradients on the Deformation and Burst Speeds of Rotating Disks**—45 pages.

2805. **An Engineering Method for Estimating Notch-Size Effect in Fatigue Tests on Steel**—35 pages

2808. **Short Bearing Approximation for Full Journal Bearings**—61 pages.

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SPECIFICATION	WHAT IT COVERS	
ASTM B202-45T Type 1 Class A	Bearings purchased by industry.	Use "Compo" H
MIL-B-5687 A Type 1 Composition A	Approved by Departments of Army, Navy and Air Force for procurement of bearings.	
U. S. Army 57-230-2 Type 1 Composition A	Bearings used by all agencies of U. S. Army including Ordnance and Signal Corps.	
SAE Gen. Instr. P221-1951 Handbook Type 1 Class A	Bearings used by automotive and related industries.	
AMS-4805	Bearings used by aircraft manufacturers and sub-contractors.	
ASTM B202-45T Type 2 Class B	Bearings purchased by industry.	Use "Powdiron" 61-P
ASTM B222-47T	Structural parts used by industry.	
MIL-B-5687A Type 2 Composition B	Approved by Departments of Army, Navy and Air Force for procurement of bearings and parts.	
U. S. Army 57-230-2 Type 2 Composition B	Bearings used by all agencies of U. S. Army including Ordnance and Signal Corps.	
SAE Gen. Instr. P2221 1951 Handbook Type 2 Class B	Bearings used by automotive and related industries.	

Just about *every* major powder metallurgy specification—whether it's issued by government agencies or by official societies—is met either by "COMPO" H (oil-retaining porous bronze) or "POWDIRON" 61-P (sintered iron). Special alloys in "COMPO" and "POWDIRON" are also available to meet specific or unusual requirements.

Write Dept. B-2, Bound Brook Oil-Less Bearing Company, Bound Brook, N. J., for details.

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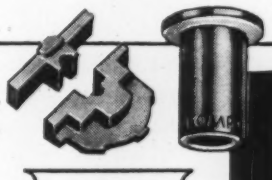

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Manufacturers of bearings and parts — Established 1883

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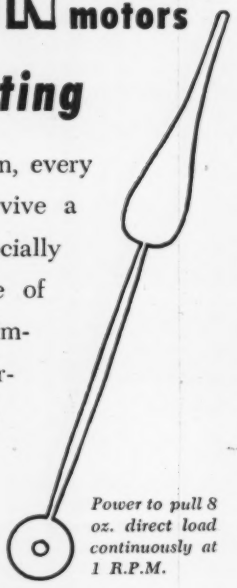
Before it passes final inspection, every SYNCHRON motor must survive a rigid operating test on a specially designed block to make sure of instant response to current impulse. No guesswork is tolerated! You can depend upon SYNCHRON for instant starting, with full power delivery.

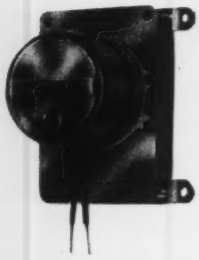


Power to pull 8 oz. direct load continuously at 1 R.P.M.

Operates efficiently in any position, and at −40° to +140° F.

easily adapted

to standard timing devices. Gear trains can be furnished to convert to any desired speed and unusual actions can be incorporated. Special timing problems are given special attention by SYNCHRON engineers.



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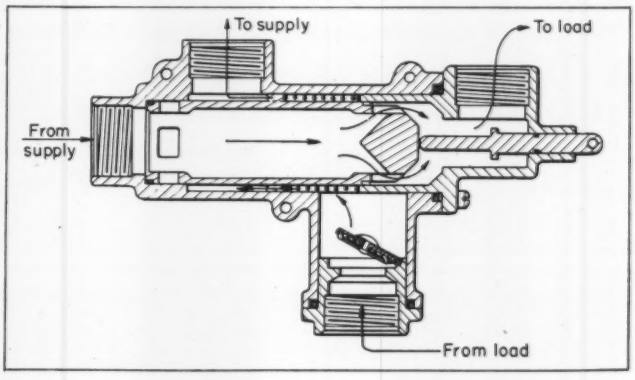
NOTEWORTHY Patents

AIR CONDITIONED COMMUTATION for dc generators increases brush life and performance during continuous operation at high altitudes. Described in patent 2,606,946, a cooling and brush lubrication system is claimed to solve the problems of excessive heating and commutator brush wear accentuated at high altitudes because of the dry atmosphere. Cooling is accomplished by circulating one or a mixture of several suitable liquids through the interior of the generator and an external intercooler. A portion of this liquid, bypassed into a separate commutator enclosure and vaporized, is used to lubricate the commutator and provide the relative humidity conditions necessary for minimum "dusting" of brushes. An invention of Alec Fisher, the patent has been assigned to General Electric Co.

AUTOMATIC CIRCUIT CUTOFF to prevent fluid delivery to faulty hydraulic circuits is afforded by a valve designed by Robert H. Davies. Assigned to the Parker Appliance Co. under patent 2,609,829, the valve is used between the supply and demand sides of a circuit. Under normal operating conditions fluid is supplied through the valve to the working circuit and returns back through the valve to the supply. An abnormal pressure drop in the working side, however, actuates a poppet which arrests the flow and diverts the fluid directly back to the supply. A check valve incorporated in the return side of the valve prevents backing up of the fluid. Poppet operation can be controlled by employing either spring, manual or electric action.

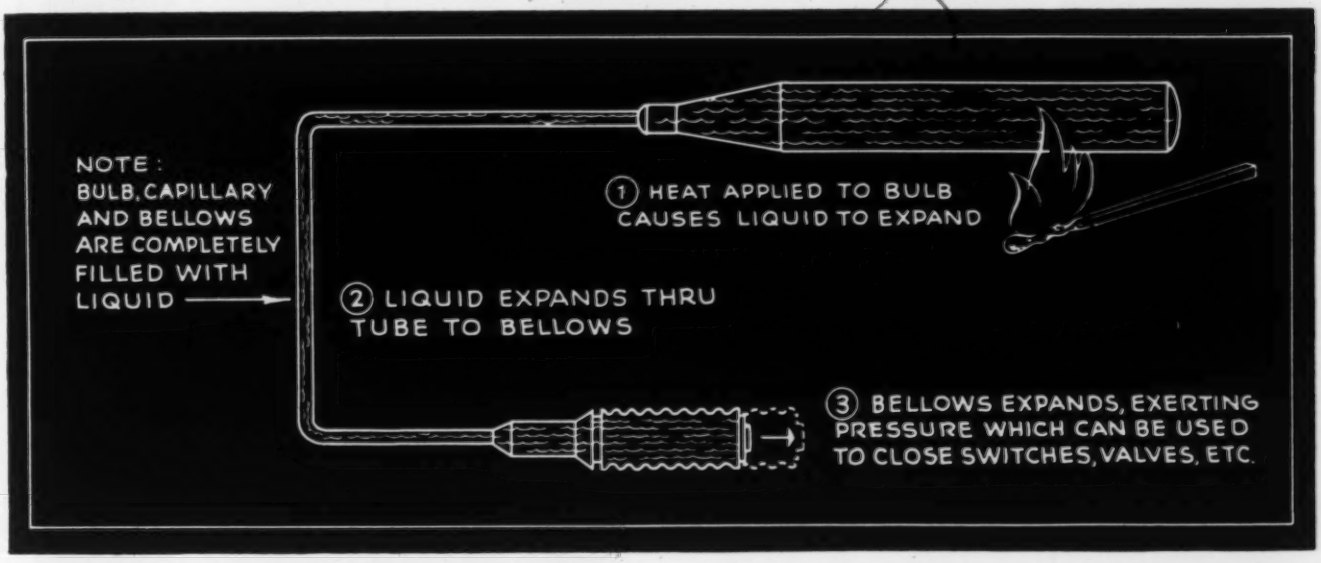


MINIMUM BREAKAWAY TORQUE when de-energized is claimed for the magnetic fluid clutch assigned

Bellows Digest

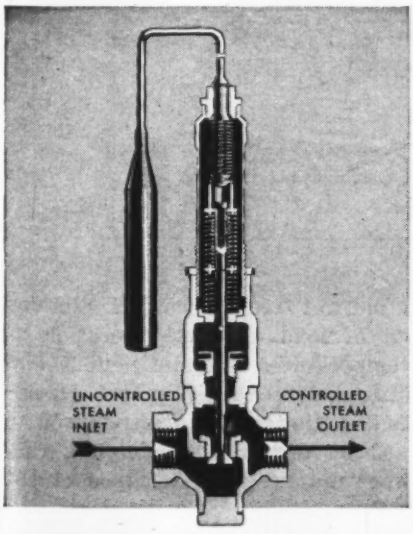
NO. 1. Liquid Filled Bellows Systems for Temperature Control.

- Permits wide temperature range and remote control with one device.

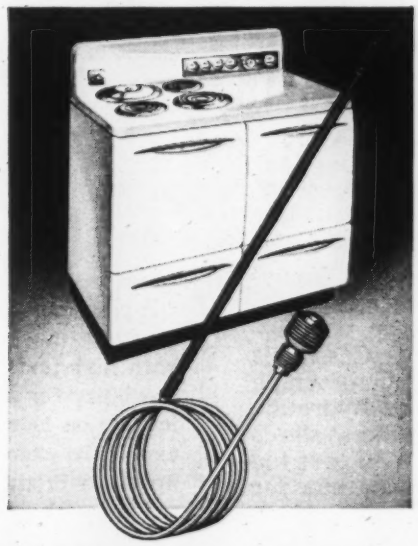

NOTE:
BULB, CAPILLARY AND BELLOWS ARE COMPLETELY FILLED WITH LIQUID
1 HEAT APPLIED TO BULB CAUSES LIQUID TO EXPAND
2 LIQUID EXPANDS THRU TUBE TO BELLOWS
3 BELLOWS EXPANDS, EXERTING PRESSURE WHICH CAN BE USED TO CLOSE SWITCHES, VALVES, ETC.

CONTROLLING WIDE RANGE OF TEMPERATURE by means of one adjusting device is a problem solved by a liquid filled Clifford bellows assembly. Such an assembly permits the use of one knob to adjust domestic cooking oven temperatures by remote control from 200° to the top limit of the oven, and industrial oven temperatures to as high as 650° or 700°. It can also be used where temperature range is low.

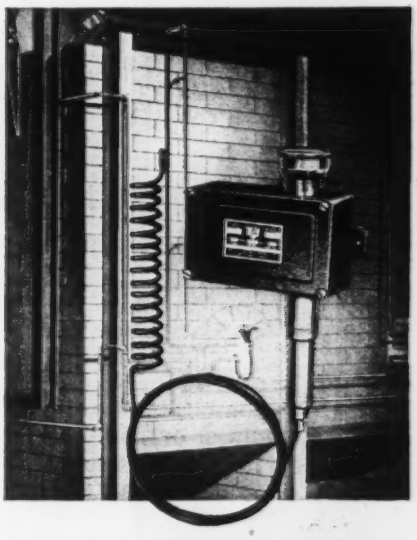
The bellows movement is closely proportional to the temperature range throughout the entire operating range of the system. The differential required to operate a device is directly related to the range of temperature to be controlled. A device requiring a wide range normally has a wide differential.



CONTROLLING STEAM for use in process equipment is a typical application for Clifford liquid filled bellows assemblies. Cross-section shows a Leslie Temperature Regulator used in cooling service. The rugged, thermostatic element is liquid expansion type with adjustable temperature range as high as 350° F.



DESIGNERS OF CONTROLS FOR ELECTRIC AND GAS RANGES use Clifford liquid filled bulb and bellows assemblies to control temperature. Bellows movement is used to operate switches that turn electrical heating elements on or off — or to turn valves on or off in controlling flow of gas.



ALL KINDS OF INDUSTRIAL PROCESSES requiring temperature or pressure control benefit by using Clifford bellows assemblies. Pictured here is a typical installation by United Electric Controls Company. This company uses Clifford bellows assemblies in temperature control of ovens, kilns, steam tables, kettles and similar equipment.

MAYBE YOU, TOO, CAN BENEFIT from the use of Clifford Hydron Bellows Assemblies. Besides controlling temperature, these flexible, leakproof, metallic bellows are also used to: (1) seal rotary shafts or packless valves against liquid or gas leakage; (2) transmit motion hydraulically to remote points; (3) provide for thermal expansion in many types of applications; (4) provide shock mountings or vibration dampening; (5) permit motion in a vacuum.

Write Clifford Manufacturing Company, 124 Grove Street, Waltham 54, Massachusetts. *Division of Standard-Thomson Corporation.* Sales offices in New York 17, Detroit, Chicago 1, Los Angeles.

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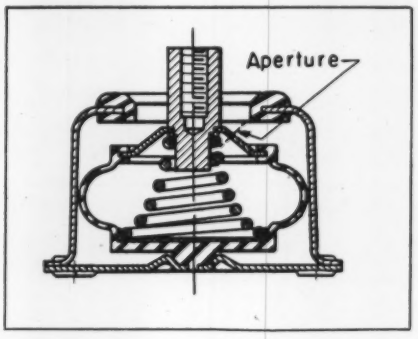
Noteworthy Patents

to General Electric Co. by Howard I. Becker under patent 2,605,876. Consisting of two concentric cylindrical rotating members, the clutch transmits power from the inner to the outer member through a magnetic mixture of lubricant and powdered iron which "freezes" in the air gap when magnetized. The usual tendency of the iron powder to pack in the air gap, an effect which results in torque transmission independent of magnetic action, has been minimized by grooving the adjacent member surfaces. In addition, the groove projections provide a more positive driving action by alignment of corresponding "teeth" when magnetized.

VARIABLE-FREQUENCY DAMPING reduces vibration amplitude in the isolator of patent 2,610,016. Serving as a mounting for delicate equipment, the device combines a conical spring and a rubber base, enclosed by a rubber diaphragm, to isolate both high and low-frequency vibrations. Features of the isolator, which was invented by Charles Crede, include large



damping capacity, a natural frequency which remains constant independent of load, effective operation at both high and low temperatures, and sufficient lateral flexibility for mounting underneath equipment. Damping action is provided by the energy loss required to expel air, compressed by deflection, through a tiny aperture in the rubber diaphragm. Assignee of the patent is the Barry Corp.

LOW-FRICTION SEALING minimizes energy losses and wear in the diaphragm type shaft seal of Patent 2,608,425, assigned to Chicago Rawhide Mfg. Co. by Louis G. Krug. Designed for use with a shaft and housing or other similar rotating parts, the seal has a projecting nosepiece which acts as a face sealing element. Radial spring fingers, clamped to the seal mounting sleeve at an angle, bear against the back of the nosepiece and maintain constant-pressure engagement, even with small end-play and angular movements of the parts. Described in several modifications, the seal construction facilitates assembly and replacement.

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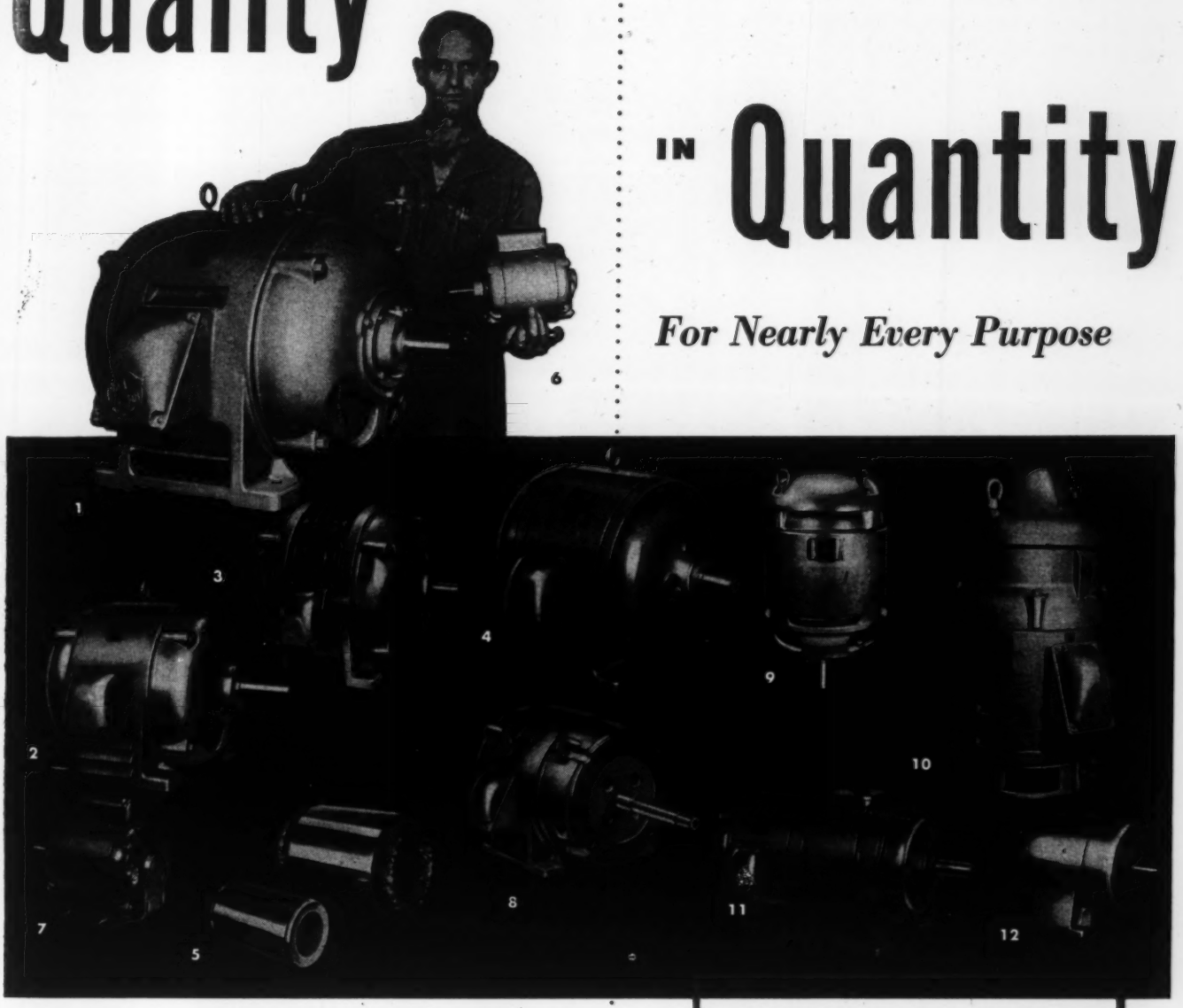

Mechanical Types: Drip-proof (1); Splash-proof (2); Totally Enclosed Non-Ventilated (3); Totally Enclosed Fan-Cooled (4); Rotors and Stators (5); Rigid Base (6); Resilient Base (7); Flanged (8); Vertical Solid Shaft (9); Vertical Hollow Shaft (10); Gear Motor (11); Special Purpose (12).

Electrical Types: Fractional H.P. ¼ to ¾. Integral H.P. 1 through 500. Single phase. Polyphase. Normal Slip. High Slip. Normal Torque. High Torque.

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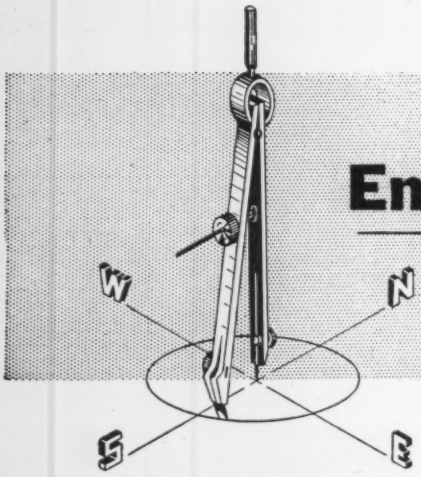


Engineering News Roundup

Jet-Powered Seaplane Has Delta Wing

The world's first delta winged seaplane, the Convair XF2Y-1 "Sea-Dart," recently began preflight trial runs on San Diego Bay. Powered by two Westinghouse turbojet engines, the high speed fighter type seaplane was built for the U. S. Navy.

The Navy's new experimental seaplane has no horizontal tail surfaces but is equipped with a triangular vertical fin and rudder. "Elevons on the trailing edge of the delta wing replace conventional ailerons and elevators. To provide better rough water landing and takeoff characteristics, the XF2Y-1 is equipped with hydro skis. This is the first application of the hydro ski to a combat type airplane in this country and, according to Navy officials, may well be the first such application in the world.

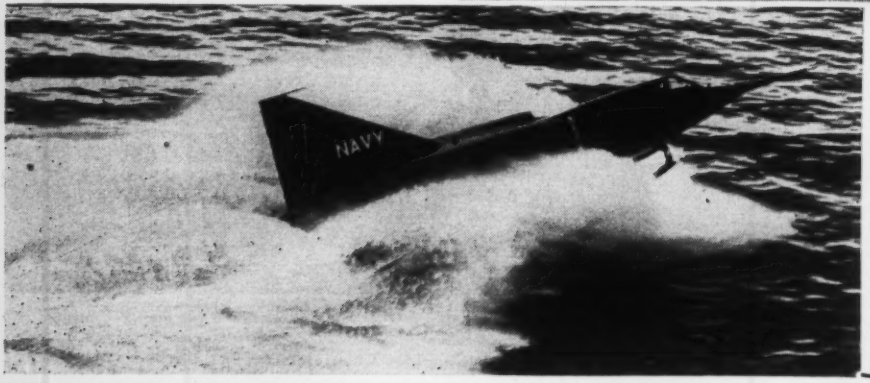
Although performance details are classified for security reasons, Navy and Convair spokesmen said the triangle-shaped craft represents a "successful blending of the high speed land-based airplane's performance with the water-based airplane's inherent versatility and mobility." No date will be set for the first flight of the XF2Y-1 until results of taxi tests are analyzed, according to Navy officials.

Contest To Award $2000 in Prizes

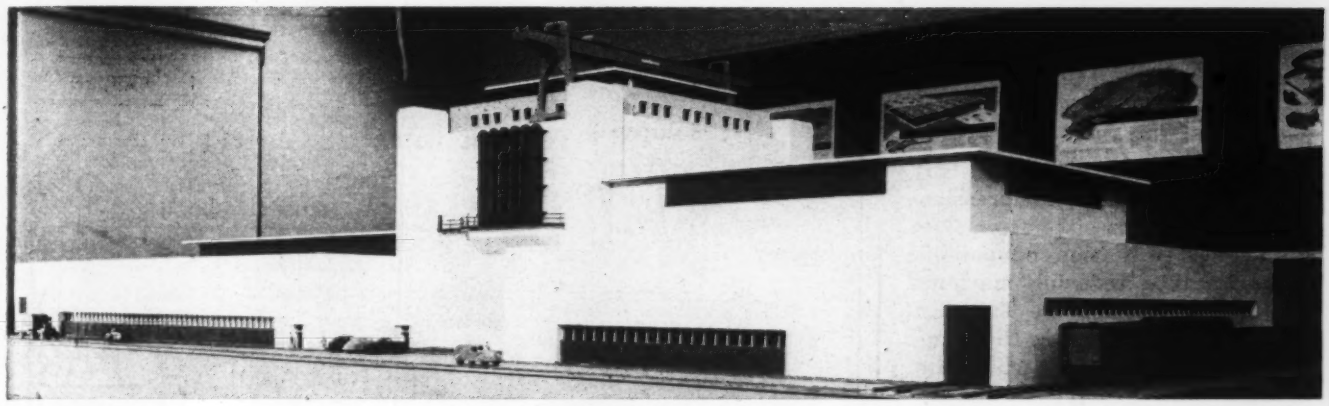
A $2000 prize competition, for the best papers on "Contributions to the Science and Art of 'Non Fusion' Welding, Brazing and Soldering" and "Practical Welding Applications," has been announced by Eutectic Welding Alloys Corp.

The contest is open to engineers, metallurgists, research investigators, welders, students, faculty members and all others qualified. Further details, contained in a complete set of contest rules, may be had by writing the Eutectic Welding Alloys Corp., Department P, 172nd Street and Northern Boulevard, Flushing 58, New York, N. Y.

This year's competition emphasizes papers of a more technical nature. Greater cash awards are being provided for papers in that category.



World's first delta-wing seaplane, Convair XF2Y-1 "Sea Dart", undergoing taxi tests at San Diego, Calif. Water skis are used for better rough-water landing and take-off characteristics



New Method For Building Huge Presses

Presses with capacities of 75,000 tons or even up to 200,000 tons can be built in the future with existing machine tools and construction equipment according to Throatless Press Co., by employing a new design principle which eliminates the conventional throat setup. This throatless press idea was originated by C. A. Van Dusen, of Van Dusen Engineering Co., Escondido, Calif.

The new company has been formed in Cleveland by the Austin Co. and the Hydraulic Press Mfg. Co. for the purpose of developing, producing and erecting the presses, which provide 360-degree access for placing and removing dies and work of any size required in closed-die forging, rubber-pad forming and die-quenching operations. A 75,000-ton press would have twice the capacity of any now in operation.

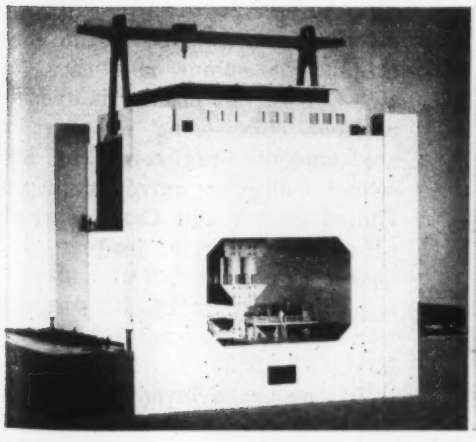
A huge monolithic concrete structure supports, suspends and houses necessary press elements and operations. This concrete mass provides the counter force required to resist the concentrated upward pressure developed in forming the largest members used in heavy jet bombers and transport planes. Columns, and head and base-frame castings used for this purpose in conventional presses are therefore unnecessary.

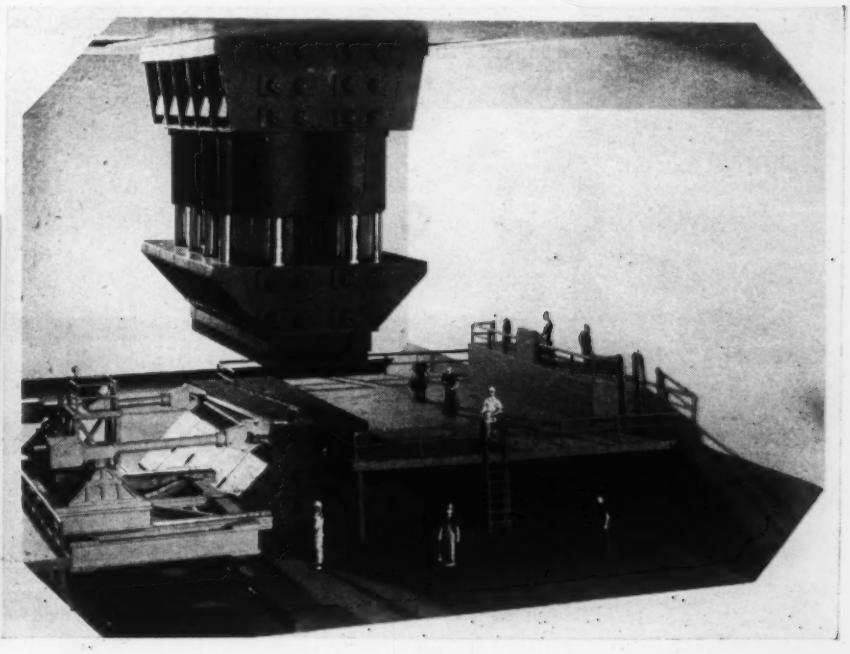
A model of the press indicates that the concrete structure will have an approximate overall height of 180 feet, 30 feet of which will be below ground level. Frame walls will be 80 feet apart, and a space 50 feet high will form the enclosure for the operating portions of the press. An indicated initial length of 120 feet could be increased; dimensions of the bed could be extended; press sections could be added to increase the tonnage or the pressing-area capacity; or a line of smaller presses could be installed in one frame.

Plans call for supporting all of the press components on the structure to utilize their weight as part of the overall counterforce and to hold runs of pressure piping to minimum lengths. Twelve 90-ton, high-pressure vessels mounted high on exterior walls will accumulate hydraulic pressures for press operation. A 100-ton capacity gantry crane on the roof will be used to raise the pressure vessels and handle pumps and compressors installed on the roof for operating the press.

Below—Exterior of model showing massive concrete housing for press

Right — Interior of model of proposed 75,000-ton press, showing 360-degree access for placing and removing dies. Manipulator at left holds a workpiece corresponding in size to largest structural wing member required in heavy jet bombers and transports



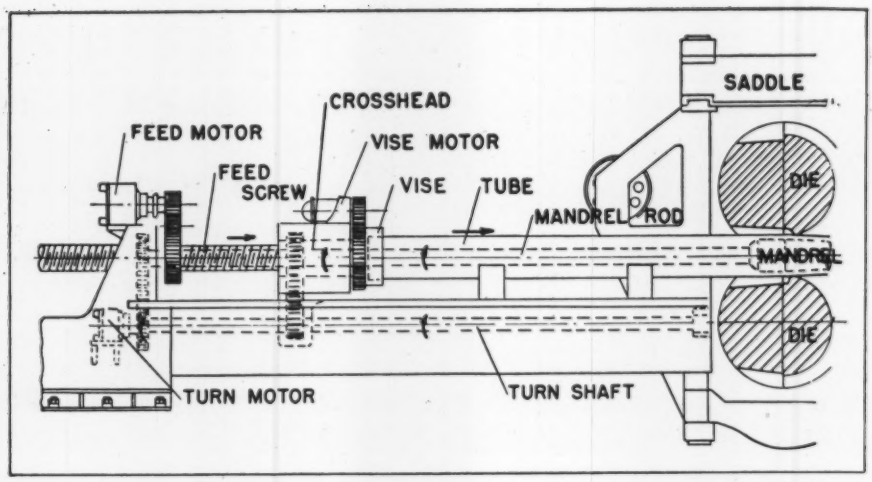


New Machines To Reduce Large Tubing

Production of compression-formed tubing in sizes from 5 to 16-inch OD will soon be possible with two tube reducing machines now being built for the Tube Reducing Corp. Extending the range of present equipment, which can process "raw" tubing up to 6½ inch OD, these new machines under construction at the E. W. Bliss Co. will handle material of 6 to 18 inches OD. One machine will use tubing in the 6 to 10-inch OD range; the other will be for the 10 to 18-inch range.

Basically, the compression-forming process is a method of cold sizing. Semicircular, taper-grooved dies are rocked back and forth over the raw tubing material, compressing the metal of the tube against a mandrel which controls the inside diameter. As the tube is fed through the reducing machine it is given a partial turn on its axis to distribute the work over the entire circumference. Advantages gained over conventional cold drawing methods include closer dimensional tolerances and improved mechanical properties and surface finish. Indicative of the tolerances possible is the accompanying table for Rockrite tubing.

Design of the new machines has been based on an analysis of present equipment. The larger machine is 100 ft. long, made up in four principal sections: (1) roll housing section at one end, (2) tube feeding means in the center, (3) drive and (4) mandrel handling equipment at the other end. Rolls are 50 inches in diameter and are supported by SKF double-roller spherical bearings. Each bearing is 48.0315 inches OD and 17.244 inches wide, weighs 5150 pounds and has a load rating of 3,200,000 pounds. The saddle carrying the rolls weighs 150 tons and is driven back and forth along rails by a pair of 13-inch hydraulic cylinders operating under a working pressure of 2200 psi. Each cylinder is driven by a separate wobble-plate pump which is claimed to be the largest of this type ever produced.



Center section of proposed tube reducing machine contains feeding mechanism which controls tubing motion to prevent jamming in the dies

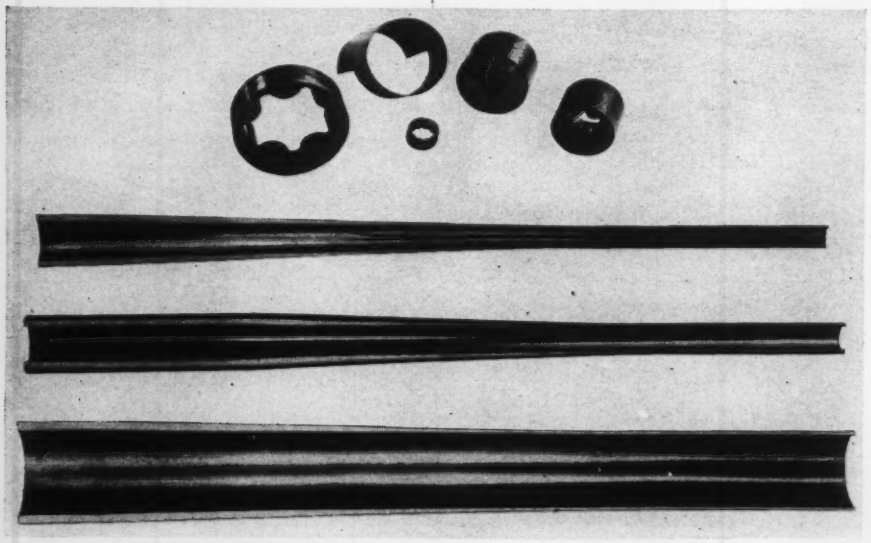
Reversal of flow and variation of pressure to cylinders is accomplished by controlling pump flow and without the use of conventional valves or accumulators.

OD (in.)	Wall Range (in.)	—Tolerances*— OD (in.)	ID (in.)
Under 1½	0.040-0.400	+0.010 −0.000	+0.000 −0.005
1½-2½	0.060-0.500	+0.012 −0.000	+0.000 −0.005
2½-3½	0.060-0.500	+0.014 −0.000	+0.000 −0.006
3½-5½	0.080-0.500	+0.020 −0.000	+0.000 −0.008

*Wall tolerances of ±5% can be used with either ID or OD tolerances given.

Biggest problems yet to be overcome are in the manufacture of the large dies. A special machine for producing the tapered groove is now being designed and experimental projects are under way to develop heat treating practices and equipment.

These parts of Rockrite tubing illustrate some of the sizes, shapes, inside contours and tapers produced by compression forming



Award Program Offers Prizes to Students

The 1952 Heli-Coil Engineering Student Design Award Program, offering cash awards for the most original or unique new uses for Heli-Coil thread inserts, is open to resident engineering undergraduate students registered in any school, college or university in the United States and Canada which offers a curriculum leading to a degree in any branch of engineering. Closing date of the competition has been extended to midnight, March 15, 1953.

To encourage inventiveness and ingenuity among student engineers

WORM GEARING—universal in its application—affords advantages for almost every power transmission job. Whether you want worm gearing sets or speed reducer units, you will find drives to meet your need in the complete Cleveland line.

Vickers Inc. hydraulic winch in operation on a Piasecki Hup-1 helicopter. Inset at left shows built-in Cleveland worm gearing.

Small Cleveland gearing speeds sea rescue

CLEVELAND worm gearing now has a part in a new kind of sea rescue. Just after the war, for the first time, a Vickers hydraulically-operated winch mounted on a helicopter hoisted two men to safety when an oil barge ran aground. Now use of the winch is standard practice, replacing hard-to-climb rope ladders previously used.

Vickers Inc. chose Cleveland worm gearing to drive the winch because it is small enough and light enough to satisfy rigid weight and bulk restrictions and is capable of governing efficiently sudden stops and starts and changes of direction involved in rescue work. To date Cleveland worm gearing has participated in over 1700 Korean missions.

Cleveland manufactures worm gearing and worm gear speed reducers in a wide range of types and sizes, large and small, to meet the requirements of any machinery builder or user. Write today for Catalog 400. The Cleveland Worm and Gear Company, 3265 East 80th Street, Cleveland 4, Ohio.

Affiliate: The Farval Corporation, Centralized Systems of Lubrication. In Canada: Peacock Brothers, Limited.

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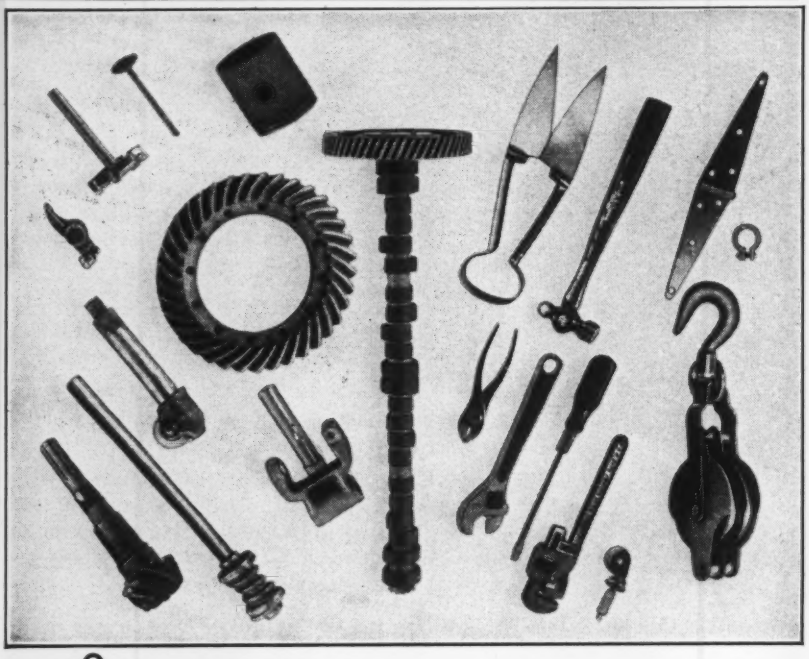
Technical Service Data Sheet
Subject: RUST PROOFING WITH PERMADINE®



Steel parts that have been Permadized and then "sealed" with a rust-preventive oil such as "Granoleum" are effectively protected from rust. And, if the oiled "Permadine" coating should be damaged, rusting will not spread beyond the area of exposure.

Note: Automotive and other rubbing parts subject to friction are usually given "Thermoil-Granodine" manganese-iron phosphate coatings for both wear-resistance and protection from corrosion.

DATA ON THE "PERMADINE" COATING

Type of coating	Zinc phosphate
Object of coating	Rust and corrosion prevention
Typical products treated	Nuts, bolts, screws, hardware items, tools, guns, cartridge clips, fire control instruments, metallic belt links, steel aircraft parts, certain steel projectiles and many other components
Government Specifications	U.S.A. 57-0-2C; Type II, Class B MIL-C-16232, Type II U.S.A. 51-70-1, Finish 22.02, Class B AN-F-20 Navy Aeronautical M-364 JAN-L-548
Scale of production	Large or small volume; large or small work
Method of application	Dip Barrel tumbling, racked or basketed work
Equipment notes	Immersion tanks of suitable capacity. Cleaning and rinsing stages can be of mild steel. Coating stage can be of heavy mild steel or stainless steel.
Chemicals required	"Permadine" No. 1
Pre-cleaning methods	Any common degreasing method can be used, Alkali cleaning ("Ridosol"), Acid cleaning ("Deoxidine"), Emulsion-alkali cleaning ("Ridosol" - "Ridoline"); vapor degreasing, solvent wiping, etc., are examples. Acid cleaning may need to follow other cleaning methods if rust or scale is present.
Bath Temperature	190° - 205°F.
Coating time	20 - 40 minutes
Coating weight range	1000 - 4000 mgs. per sq. ft.
Technical Service Data Sheets	No. 7-20-1-2 T.M. No. 5

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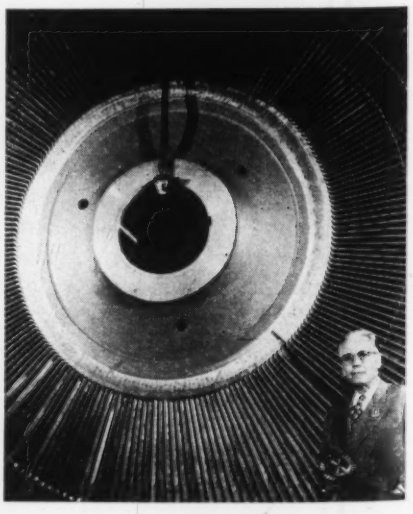
and to supplement class work with practical industrial problems that will help prepare students for their transition into industry, the program offers a $1000 first award, $500 second award and $250 third award. Merit awards, the number of which will be determined by the judging board, will carry a cash award of $100 each.

The six-man judging board is composed of Colin Carmichael, editor of MACHINE DESIGN; A. Baker Barnhart, industrial designer and partner, Raymond Loewy Associates; Karl H. Tietjen, consulting engineer for Ingersoll-Rand Co. and partner in Nowland & Schladermundt; Francesco Collura, industrial designer and founder of Francesco Collura Associates; George F. Nordenholt, editor of *Product Engineering;* and Austin H. Church, professor of machine design and chairman of the Mechanical Engineering Department of New York University.

A post card or letter addressed to "Design Award Program," Heli-Coil Corp., Danbury, Conn., will register a student as an official participant in the competition. Complete engineering data and other necessary information will be sent by return mail.

♦

Smallest and largest turbine wheels manufactured by General Electric last year are compared in size. The smallest wheel, held by turbine division manager Glenn B. Warren, is less than 6 inches in diameter and revolves at 34,000 rpm in a supercharger. The largest turbine wheel has a diameter of 14 feet and revolves at 1800 rpm in a steam turbine



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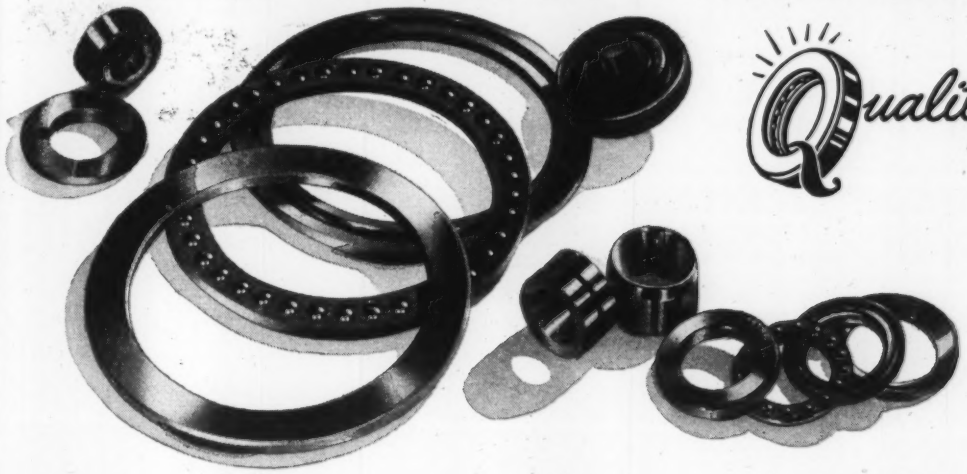

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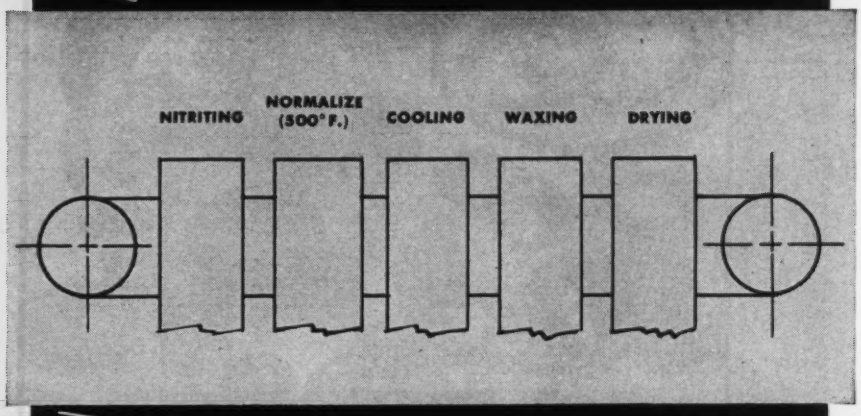


help spring producer boost output 350% in 30% less floor space!

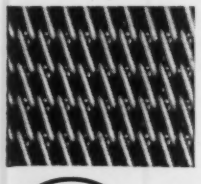
110 old-fashioned hand trucks no longer needed! 15 truck operators freed for more productive work! Floor space requirements cut by 30% . Output rose from 290,000 pieces in 24 hours to 680,000 pieces in 16 hours, *an hourly increase of 350% !*

These were the results of this installation of a 98′ Cambridge wire mesh belt in a large spring producing plant. The moving belt gives continuous production, eliminates the need for hand trucks in transferring the work from one step to the next, assures uniformly processed work.

Perhaps Cambridge wire mesh belts can help you get similar savings. They're available in any metal or alloy, mesh or weave, length or width. They can be used under practically any conditions . . . from temperatures as high as 2100° F. down to sub-zero, for handling work through simple water rinses or highly corrosive acid sprays, for carrying small delicate parts or heavy, bulky loads. All-metal belt construction assures long life and freedom from damage. Open mesh permits free drainage of process solutions or free circulation of process atmospheres.

WHY NOT CALL IN YOUR CAMBRIDGE FIELD ENGINEER?

You can rely on his experienced advice to recommend just the right type of wire mesh belt for your process. Look under "Belting-Mechanical" in your classified phone book for the Cambridge office nearest you.



Cambridge Duplex Weave, one of the most widely used specifications for continuous heat treating.

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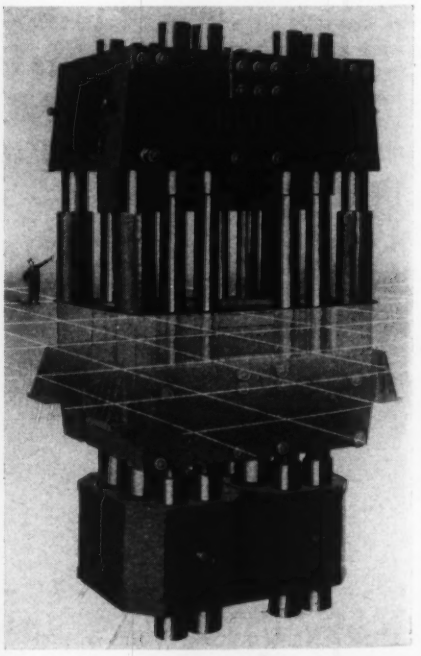
Engineering News

Air Force Orders Two New Heavy Presses

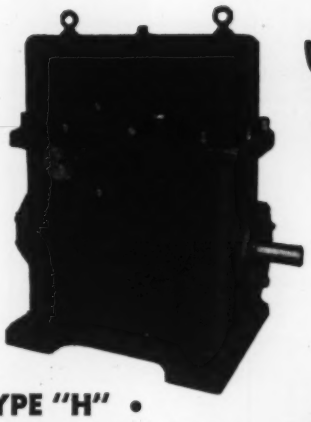
Two new heavy forging presses of 25,000 and 35,000 ton capacity are to be installed at a new Air Force plant at Newark, O. Presses are scheduled for delivery by early 1954, and the plant, to be operated by the Kaiser Aluminum and Chemical Co., is expected to be ready for production by the end of that year. To be built by the E. W. Bliss Co., the presses will produce large magnesium and aluminum forgings for aircraft.

Overall height of the 35,000 ton press will be 72 feet with 39 feet below the floor level and 33 above. Total weight will be about 5000 tons; 3400 tons of this amount is in the moving parts of the press, which include the crown, tie rods and cylinder container. The Bliss design, in a sense, is comparable to the large 33,000-ton German Schloeman press turned upside down. It is mounted on what would conventionally be called the slide, and the base and tie rods are the moving members. This accounts for the large portion of the total weight being in the moving members. Advantages claimed for this type of construction are that the 3400-ton moving weight helps to provide the 35,000 ton capacity



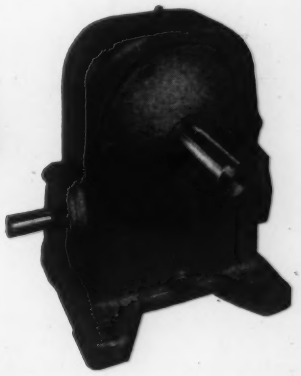
D. O. James

ESTABLISHED • 1888



TYPE "H" •

Horizontal or Vertical Drive— Each drive type comes in 15 sizes, with ratio ranges of 5.6:1 to 100:1 and from .06 to 206 horsepower.



TYPE "S" •

Horizontal or Vertical Drive— Each type available in 8 sizes, ratio range of 5.66:1 to 100:1 and from .04 to 15.6 horsepower.

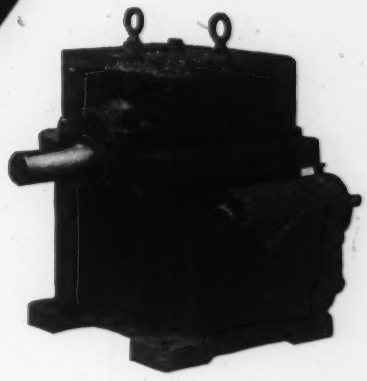
WORM GEARS AND WORM GEAR REDUCERS

MOTORIZED •

Horizontal or Vertical Drive— Each drive type comes in 11 sizes, has ratio range of 5.6:1 to 100:1, with ⅛ to 30 horsepower, driven speeds of 310 r.p.m. to 17.4 r.p.m. Vertical drive slow speed shaft extends either upward or downward.

DOUBLE •

Horizontal or Vertical Drive— Each drive type available in 13 sizes, ratio range of 130:1 to 10000 and from .004 to 59.7 horsepower. Vertical drive slow speed shaft extends either upward or downward.

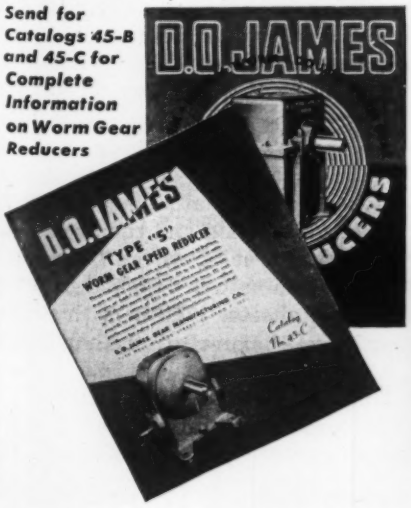


WORM GEARS

Generated on tangential feed hobbing machines by tapered and ground hobs. Made from 1" to 100" in diameter and from 24 DP to 1 DP.

Catalogs are available to users of Gears and Gear Reducers—containing valuable engineering data, specifications, weights and prices.

Send for Catalogs 45-B and 45-C for Complete Information on Worm Gear Reducers



D. O. JAMES Worm Gears and Worm Gear Reducers are designed and manufactured to have maximum inbuilt strength and to assure dependable *on-the-job* performance. The many and repeated installations of these reducers testify to their operating superiority and adaptability.

D. O. James GEAR MANUFACTURING COMPANY

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SINCE 1888—MAKERS OF ALL TYPES OF GEARS AND GEAR SPEED REDUCERS

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Use
FAIRFIELD
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DESPITE all the care you lavish on the design and construction of your product, its successful performance may ultimately depend on a few, relatively small gears. That's why it makes good sense to use only gears of *established quality*. FAIRFIELD GEARS have proved themselves "in use" on an almost limitless range of industrial products during the past 30 years. They are made-to-order—any type, and in a wide variety of sizes—to meet your special needs.
On your next gear problem, call in FAIRFIELD at the start. FAIRFIELD engineers are qualified to make expert recommendations that may save you time, money and future concern about gear performance in your product. Write for interesting, illustrated brochure.
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for FINE GEARS
2307 South Concord Road, Lafayette, Indiana

Engineering News

and the main cylinders of the press are located near floor level, allowing pumps and prefill tanks to be located close to the cylinders and still be in an accessible, floor-level location.

Available die area is 24 by 12 feet. Maximum daylight opening, the distance from the bolster plate to the bottom of the crown, is 11 feet. Approach and return speeds are 300 inches per minute, and pressing speed can be accurately controlled between 6 and 150 inches per minute. Main ram capacity can be controlled from 7000 tons to 35,000 tons, the maximum.

Hydraulic fluid used to power the eight press rams is specially treated water. The water is furnished to the main cylinders at pressures up to 5400 psi. Six pumps, each having a capacity of 500 gpm, against a head of 5500 psi, are used. Each pump has seven cylinders and is driven by a 1500-hp motor.

Announce Production Of New Laminate

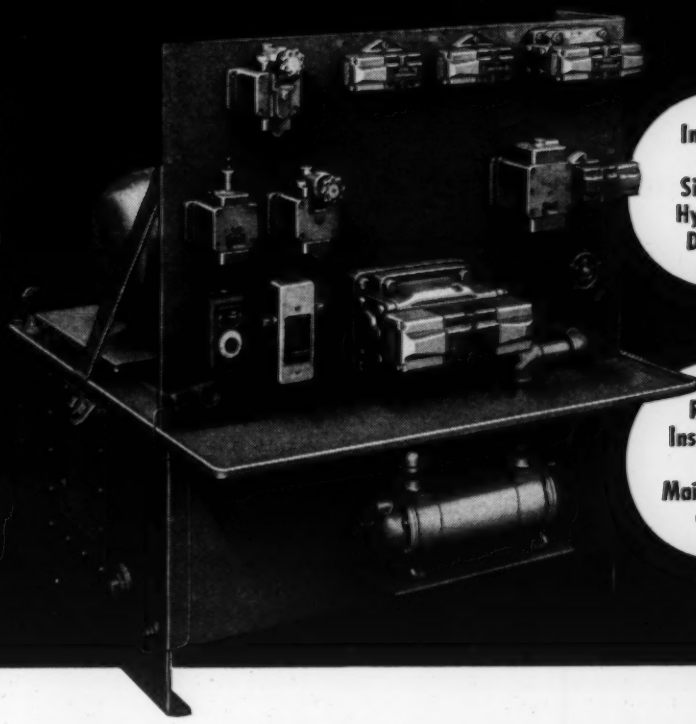
A new grade of glass mat melamine laminate which combines high fire and arc resistance with good mechanical and chemical properties will soon become standard for all Navy electrical power and lighting applications. Produced by Synthane Corp. and designated G-8, the new laminate has electrical properties comparable to the continuous filament glass-base material NEMA Grade G-5.

The new material is composed of a glass fiber mat impregnated with melamine resins. Thus its mechanical properties are less directional than those of a woven-base laminate. Lower production cost is claimed because weaving operations are eliminated. Also, no lubricant is applied and removed later as in the case of woven fibers.

The laminate is supplied in 36 by 36-inch sheets, 1/16-inch thickness or more. Flexural strength of a flat, ½-inch thick sample is 24,000 psi in lengthwise direction and 20,000 psi in crosswise direction. Impact strength of a similar sample is 6.0 ft-lb lengthwise, 6.0 in notch crosswise. Bond strength is 1200 lb.

It Takes MORE than a Collection of Parts

To Make A VICKERS CUSTOM BUILT POWER UNIT



Improve and Simplify Hydraulic Design

Reduce Installation and Maintenance Costs

A Vickers Custom Built Power Unit is much more than a collection of parts . . . just as the machines you build are more than the castings, shafting, gears, motors, etc. that go into them.

The Vickers Unit is designed and built with the "know-how" obtained during more than a quarter century of experience in practically every kind of hydraulic operation, plus a thorough understanding of your needs. It is built exactly to your individual requirements. All necessary pumps, valves, intermediate piping, oil reservoir, motors, controls, etc., are in one compact and self-contained "package". It includes all needed hydraulic accessories such as oil filters, air cleaners, oil level gauges, fittings, etc. Hydraulic connections may be grouped in a conveniently located manifold.

The result is simplification of hydraulic design and important savings in installation and maintenance costs. Vickers undivided responsibility for the entire hydraulic control system is another important advantage to both the machine builder and his customer. • Write for new Bulletin 52-45.

VICKERS Incorporated

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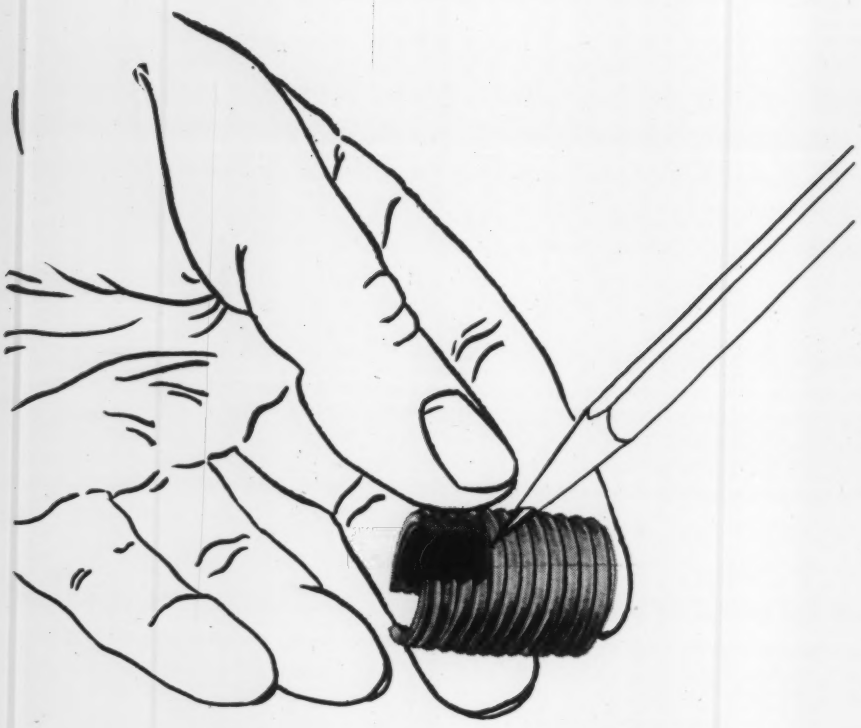
ENGINEERS AND BUILDERS OF OIL HYDRAULIC EQUIPMENT SINCE 1921

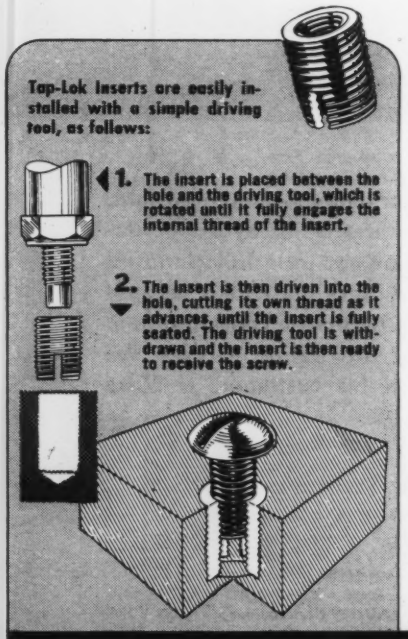


Tap and insert in one operation—

—with TAP-LOK INSERTS*

The Tap-Lok Insert offers an effective, low-cost method of preventing stripping of tapped threads in softer-than-steel materials. It is a steel or brass bushing threaded internally and externally, and provides a hard, long-wearing thread surface.

Slotted segments at one end of the insert enable it to tap its own thread as it is turned into a cored or drilled hole equal in size to a tap drill hole for its external thread. This self-tapping feature eliminates the separate tapping operation required by other types of bushings. The saving in time and labor makes it the most practical and economical method of tapped thread protection that has ever been devised.


Tap-Lok inserts are easily installed with a simple driving tool, as follows:
1. The insert is placed between the hole and the driving tool, which is rotated until it fully engages the internal thread of the insert.
2. The insert is then driven into the hole, cutting its own thread as it advances, until the insert is fully seated. The driving tool is withdrawn and the insert is then ready to receive the screw.

The insert retains its seat firmly against vibration. It affords maximum torque-and-pull resistance and is not subject to the time-consuming failures of molded-in and cast-in inserts. Widely used as original equipment, the Tap-Lok Insert is ideal also for salvage and repair of stripped threads.

Send for descriptive folder.

Also manufacturers of Groov-Pins for positive locking press fit.

*Reg. U.S. Pat. Off.

GROOV-PIN TRADE MARK REG U.S. PAT OFF

GROOV-PIN CORPORATION

1129 Hendricks Causeway, Ridgefield, New Jersey

Engineering News

ENIAC's Memory Improved By Electronic-Magnetic Unit

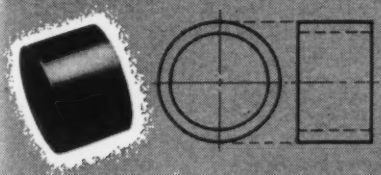
Built to speed the work of the Army's ENIAC (Electronic Numerical Integrator and Calculator), a new fast-access memory apparatus employing both electronic and new magnetic techniques stores and releases numbers at the rate of 50,000 per second. Designed and constructed by the Research Div. of Burroughs Adding Machine Co., the new unit will be used with ENIAC in the Ballistics Research Laboratory at Aberdeen Proving Grounds.

ENIAC's present vacuum-tube memory can now remember a maximum of 20 numbers; any overflow is transferred in code on punched cards to which the machine refers frequently. The new unit, having a capacity of 100 numbers, will increase the computer's memory power six-fold and will enable it to deal with bigger problems without repeatedly consulting the cards. Also, computation will be accelerated.

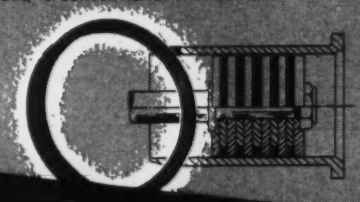
Heart of the memory unit consists of 4100 individual cells located in "addresses" or registers on four panels. There are 100 addresses, each of which will remember a number of up to ten digits. Each cell consists of a small doughnut-shaped core of magnetic metal

Four large panels of the memory unit contain hundreds of individual magnetic cells and can store or release 50,000 numbers per second

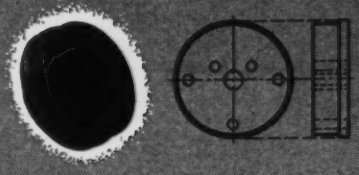
● **HIGH SPEED, HIGH TEMPERATURE SELF-LUBRICATING BEARINGS** — Applicable for pumps handling steam condensate at over 300° F at 300 PSI. Capable of withstanding high speeds and relatively heavy loading without conventional lubrication. Ideal for inaccessible locations.



● **SELF-LUBRICATING PRESSURE RINGS ELIMINATE OIL IN COMPRESSED AIR OR GAS STREAM** — Mechanically strong, chemically inert, impart no taste or odor. Eliminate contamination in food processing, and danger of explosion of combustible gases due to conventional lubricants.



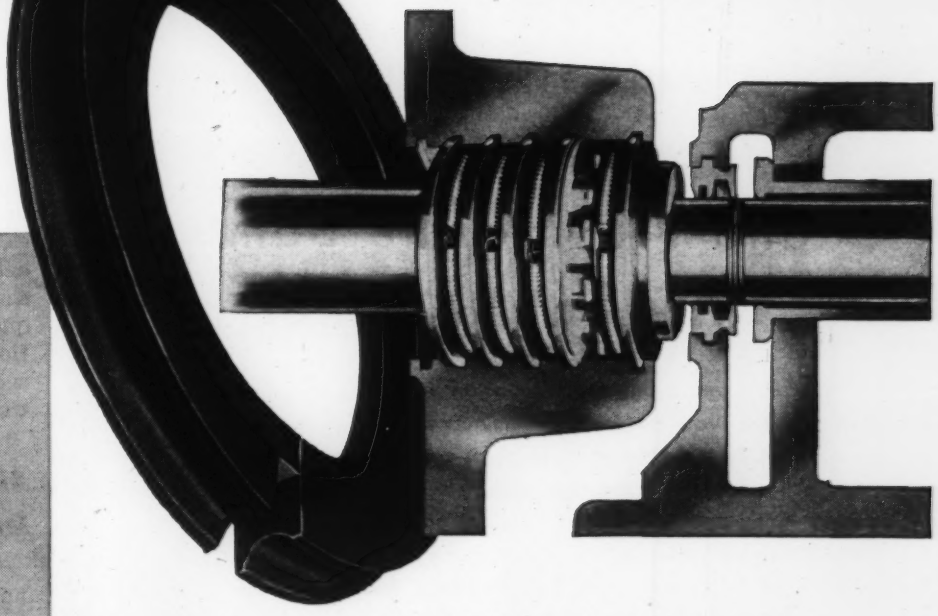
● **MORGANITE CARBON SEALS FOR HIGH PRESSURES AND HIGH SHAFT SPEEDS** — Mechanical seals withstand corrosive chemicals, grit, high shaft speeds. Seal highly volatile fluids under extreme pressures. Mechanically strong. Provide perfect sealing free of warping and gumming.



SELF-LUBRICATING

Turbine Seals

HIGH PRESSURE



- **HOLD LIVE STEAM AT HIGH PRESSURE**
- **FUNCTION WITHOUT LUBRICATION**
- **RESIST CORROSION**

Inaccessibility is no factor because they have inherent self-lubricating qualities which last for the life of the seal. Full retention of steam from cold start to full load is assured. Specify Morganite Seals Rings and Washers for maximum operating efficiency and minimum shut-down time.

FOR ADVICE ON YOUR HIGH PRESSURE SEALING PROBLEMS, SEND INQUIRIES TO —

The Morganite engineering staff will be glad to consult with you on specific applications. There is no obligation.

Manufacturers of

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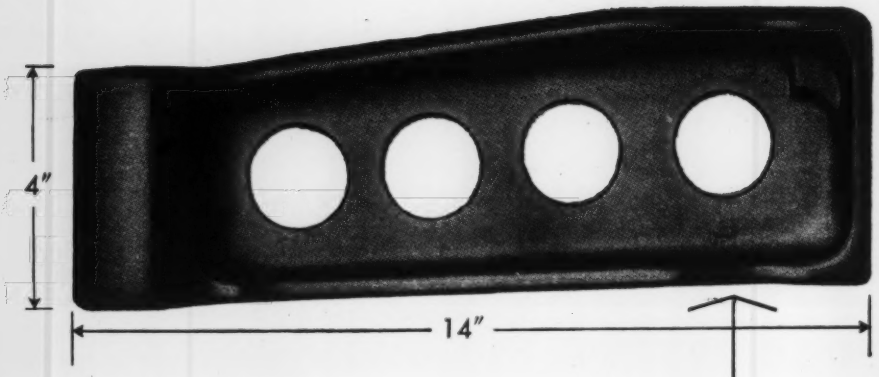

From Jet Bomber Parts
to Gas Range Burners

MUELLER BRASS CO.

Aluminum Forgings Save Weight, Save Finishing Time and Provide the Same Strength as Steel

If weight and strength are important factors in your product, then Mueller Brass Co. forged aluminum parts may be your best bet. Mueller aluminum forgings weigh only ⅓ as much as steel, yet they are approximately as strong. They make ideal parts for many applications and they are particularly desirable as parts for high speed rotating and oscillating machines because they reduce vibration and bearing loads, thus causing less wear on other parts. They possess good dimensional stability and retain their mechanical properties at high speeds and reasonable temperatures. The smooth, bright surfaces save machining time and eliminate costly finishing. Mueller Brass Co. can forge aluminum parts to your specifications in any practical size and shape from any of the standard or special alloys. Write us today for complete information.

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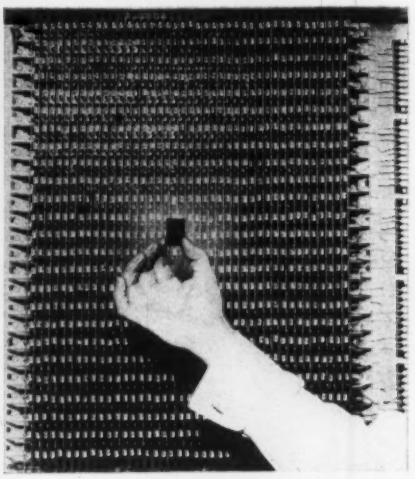


Basic storage unit of memory device is doughnut shaped core of magnetic metal encased in plastic

encased in plastic.

Numbers in a problem to be solved by ENIAC are coded into electrical pulses and directed to specific memory cells. The cells are thus polarized in combinations representing the numbers in the problem. With the figures stored, ENIAC is instructed what to do with figures of certain addresses in the memory. Interrogation pulses are sent out to the addresses to determine various numbers. Pulses sense the polarity of the cells in question and transmit this information back to ENIAC's computing section where it is used in working the problem.

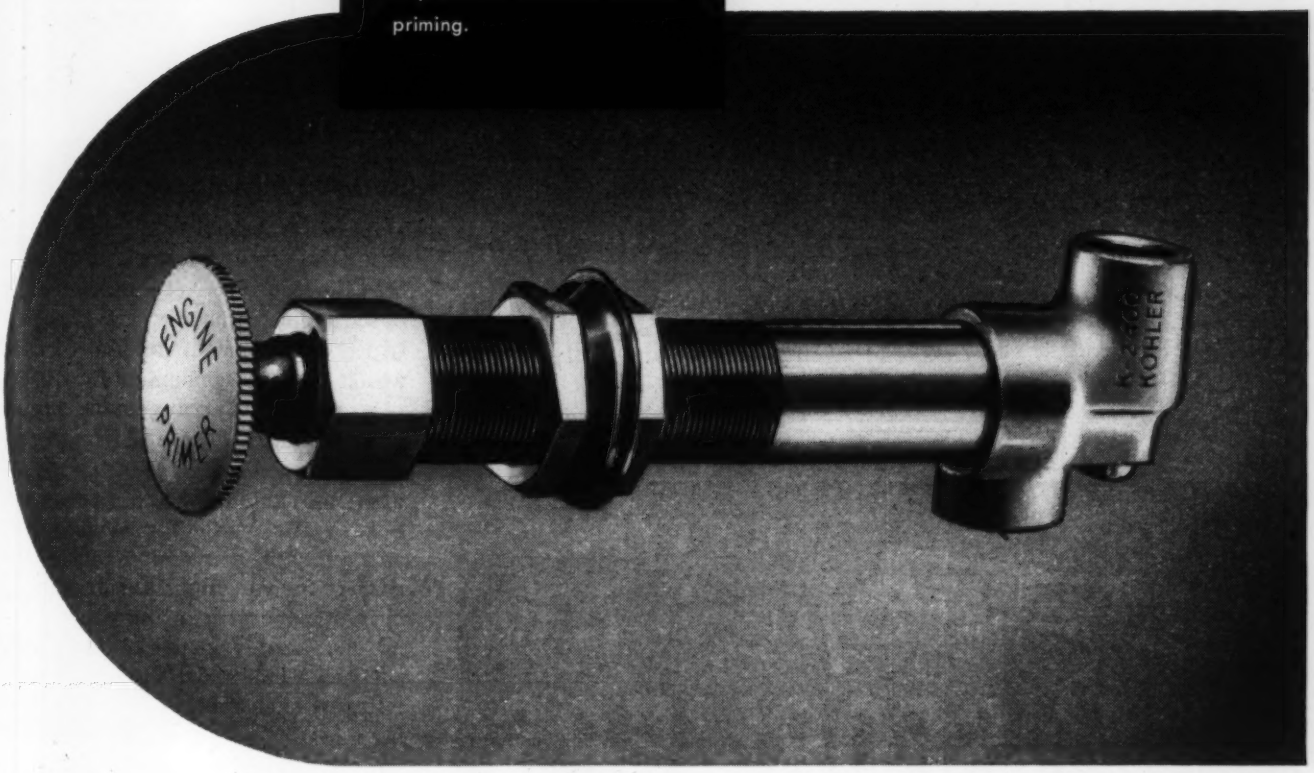
Air Materiel Command Has Index of Approved Item Names

The index of approved item names section of the Federal guides to standard nomenclature, for use on drawings and other documents prepared by contractors for the Air Force, is now available in limited quantities.

The guide provides contractors with consistent, uniform nomenclature for identification of all items purchased by the Defense Department. Previously items were purchased and identified separately and under various nomenclatures by each branch of the service.

At this time, only the index section is being distributed to Air Force contractors and manufacturers, who may receive the alphabetic Part I of the guide on request

Kohler Engine Primer—specified by manufacturers of Diesel engines and personal airplanes for efficient, reliable priming.



KOHLER PRECISION CONTROLS

- **Aircraft**
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Kohler Co. is a leading supplier of precision controls, including pneumatic, hydraulic, fuel valves and fittings, to manufacturers of jet engines, military, commercial and private aircraft, agricultural and industrial test equipment and Diesel engines.

Facilities for forging, die casting, machining, anodizing, are maintained all in one plant—with an experienced organization skilled in precision workmanship.

Our engineers develop, for volume production, controls to specification. Write for illustrated booklet.

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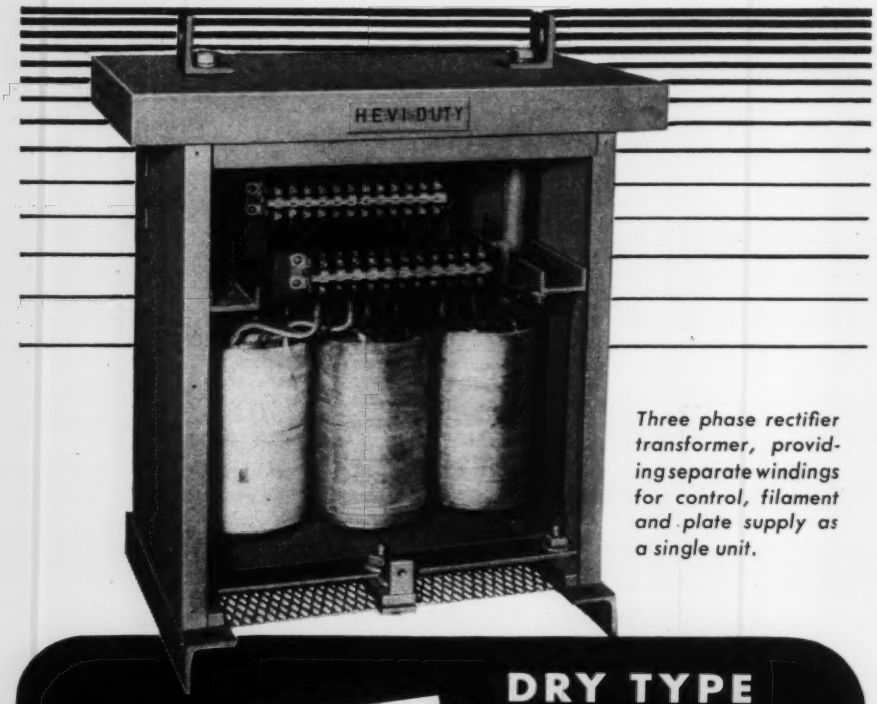
KOHLER OF KOHLER

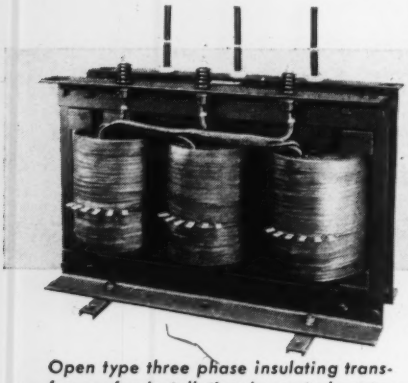
PLUMBING FIXTURES • HEATING EQUIPMENT • ELECTRIC PLANTS • AIR-COOLED ENGINES • PRECISION CONTROLS



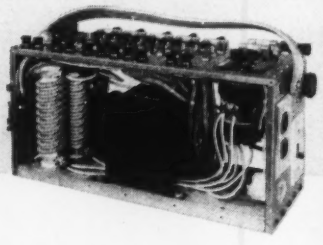
Three phase rectifier transformer, providing separate windings for control, filament and plate supply as a single unit.

DRY TYPE
HEVI-DUTY *Specialty*
TRANSFORMERS

Here are three typical examples of transformers that have been designed by Hevi Duty engineers for specific applications. Whether your needs are large or small for either standard or special transformers, you can depend on the engineering skill and modern manufacturing facilities of Hevi Duty Electric Co. to serve you.



Open type three phase insulating transformer for installation in control center cubicles. Primary voltages to 15 KV are available.



Hevi Duty, 3 KVA type SI0 transformer is part of a portable test box used by electric utilities for testing protective relays in the field.

HEVI DUTY ELECTRIC COMPANY
MILWAUKEE 1, WISCONSIN
Heat Treating Furnaces... Electric Exclusively
Dry Type Transformers *Constant Current Regulators*

Engineering News

to the Cataloging and Packaging Division, Directorate of Supply and Services, Headquarters, Air Materiel Command, Wright-Patterson Air Force Base, Ohio, attention MCSISD.

Test Predetermines Rocket Fuel Consumption

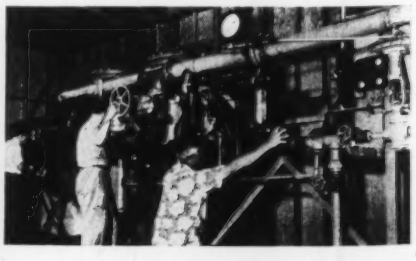
A factor which must be determined in testing Ryan Aeronautical Company's rocket motors which power guided missiles and high altitude rockets is the amount of fuel which will be consumed in flight.

A flow test arrangement pours huge volumes of water through the rocket motors and carefully measures the amounts and pressures. Substituting water for rocket fuels and applying conversion factors to correct for varying viscosities, densities, temperatures and other variables makes it posible to determine the complete hydraulic characteristics of each motor without firing it.

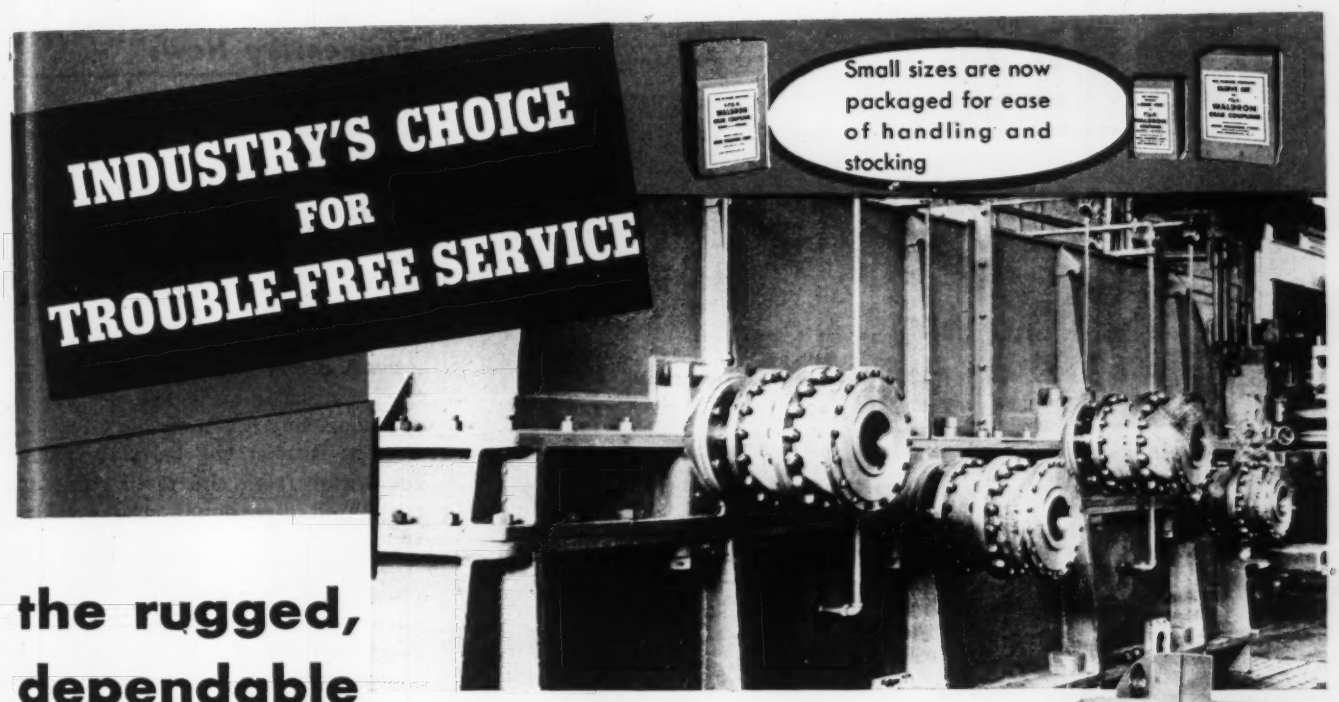
Water, which is brought in through a 5-inch line, can be forced through the system at the rate of 2 tons per minute. It is regulated in pressure, measured and filtered before coursing through the motor.

Instruments in the test setup include a flow meter, which indicates rate of flow in pounds per second, and pressure gages, which show pressures in psi. From these figures, engineers calculate the pressure drop through the motors and develop the hydraulic characteristic curves needed to chart performance.

The cleanest water in San Diego—filtered to remove particles larger than 10 microns in diameter — is gushed through this flow test arrangement which tells Ryan Aeronautical Co. engineers how much fuel a rocket will consume in flight



INDUSTRY'S CHOICE FOR TROUBLE-FREE SERVICE

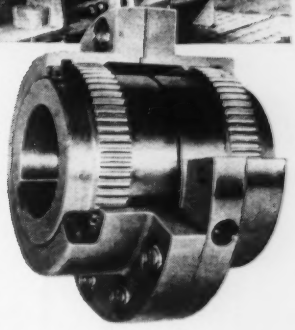


the rugged, dependable

WALDRON

ADVANCED DESIGN

GEAR COUPLINGS



NEW!
WALDRON Junior GEAR COUPLING
First light weight, inexpensive coupling of gear type construction for nominal bores—3/8", 1/2", 5/8", 3/4". Made of unbreakable nylon. Weight 2½ ozs. Non-corrosive, non-magnetic. Requires no lubrication. Full particulars on request.

built to eliminate the usual sources of costly coupling failure

The most dependable couplings are those of gear type construction. And throughout industry the WALDRON Gear Coupling is recognized as the most advanced in design and construction of all gear couplings. Its popularity stems from its many design refinements and operating advantages which combine to insure longer service life. Features such as WALDRON all steel construction, one piece cover sleeve, crowned gear teeth, longer lining up surface, automatic lubrication, less rotating weight and others, afford extra protection against costly shutdowns for repairs or replacements. Performance records of WALDRON Gear Couplings over many years have made them first choice of the leading equipment builders. For your gear coupling—specify WALDRON.

Waldron Couplings embody more than 40 years of coupling building experience. Available in all types and sizes. Design easily adapted for special applications. Write for descriptive catalog and specific engineering data.

JOHN WALDRON CORPORATION

Waldron Series "A" and Junior Gear Couplings Francke Pin Type Coupling Anchor-Waldron Overload Cut-Outs

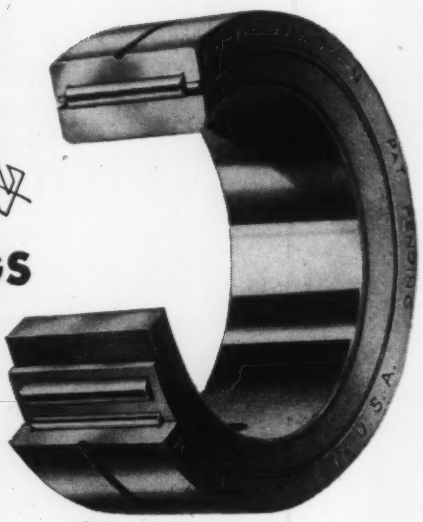
NEW BRUNSWICK • NEW JERSEY

Sales Representatives In Principal Cities • In Canada—Peacock Brothers, Ltd.

RBC

PITCHLIGN

ROLLER BEARINGS

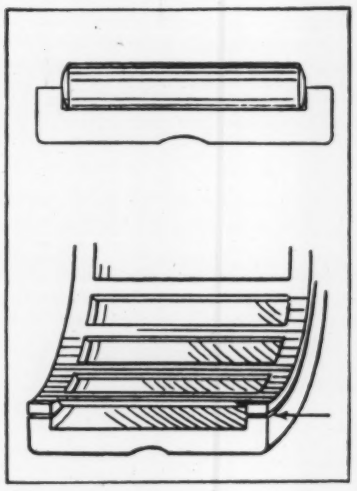


...have Integral Flanges

Rollers are located axially by direct contact with the flanges which present a continuous surface to the ends of the rollers. As a result, it is impossible to have end thrust against the cage.

Integral flanges support the free-floating cage which does not ride the rollers, but acts only to align them at their pitch circle. Flanges serve also to retain lubricant.

PITCHLIGN is interchangeable with precision needle bearings. Get all the facts!



PITCHLIGN
TRADE MARK
ROLLER BEARINGS

GET THE FACTS!

Write Today

Ask for Bulletin SF-266

ROLLER BEARING COMPANY OF AMERICA • TRENTON, N. J.

Engineering News

Jet "Eggbeater" Utilizes Cog Belts

The Army's new XH-26 one-man pulse jet helicopter incorporates a new application of the cog belt principle of power transmission. Designed primarily for observation and reconnaissance work, the plane has no gears or transmissions, but relies on a system of Dayton Rubber cog belts to transfer power from the main rotor to the small directional rotor at the tail.

In designing the system for application of a maximum performance belt drive, aeronautical engineers specified a belt that could carry more horsepower for its weight, size by size, be resistant to slippage of short centers over small pulley diameters and still be flexible for efficient operation.

The XH-26 is the smallest and lightest helicopter ever procured

by the Army Ground Forces. It stands 6 feet high and weighs 300 pounds. It can lift twice its own weight, fly 80 mph and stay in the air for 90 minutes without refueling. Manufactured by the American Helicopter Co., it is small enough to be carried aboard larger aircraft and can be dropped by parachute and assembled for flight in 20 minutes.

Exposition To Feature Metals and Machinery

The Western Metal Exposition, to be held in Los Angeles March 23-27 will be "the largest and most important display of metals and machinery yet blueprinted for the Pacific Coast," according to com-

Precision casting news

by Arwood Engineers

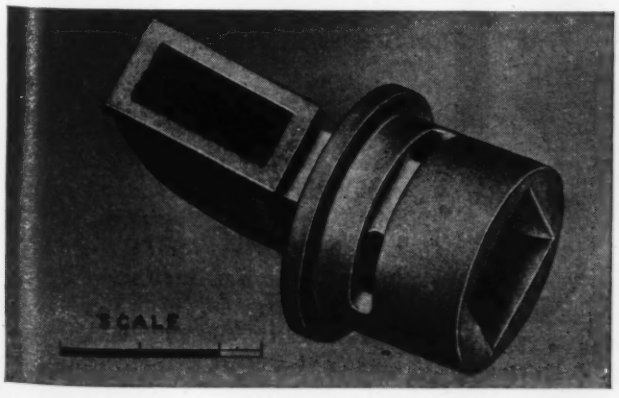
Each month Arwood illustrates an unusual casting. This month it is a magnesium elbow produced for radar equipment.

The first point is that because of design and shape this casting is practically impossible to produce by any method except precision casting.

Important, too, are these facts. The internal waveguide dimensions are held to a maximum tolerance of ± .003 with no further finishing required. With a maximum wall thickness of .050 the part must withstand a pressure test of 35# p.s.i. and pass X-ray requirements.

But magnesium is only one metal that Arwood casts. Others are aluminum, copper, bronze, brass and various steels. Details are in our booklet, "Alloy Selection and Design for Investment Castings."

TIP TO DESIGN ENGINEERS—When a Product Design Engineer works closely with our engineers the impossible often becomes possible. Through the ingenuity of our engineers and tool designers, the part shown was produced as a complete unit and seven parting lines were eliminated.

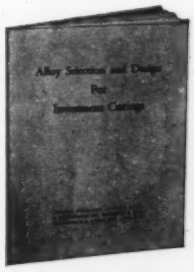


from Arwood

Wright Bronson, Junior and Senior

Both Wright Bronson, Senior and Junior, are doing outstanding sales engineering work for Arwood. They consider engineering service the greatest single factor in their successful Arwood operation. Because both are graduate engineers from Cornell they are able to give sound and valuable advice to their many friends in Ohio.

Wright Bronson, Jr., joined Arwood in 1948 and soon made himself felt in the organization. In 1951 his father brought his valuable experience to Arwood to make it a team, something they had been looking forward to for years.



For more complete information write for our booklet, "Alloy Selection and Design for Investment Castings."

☆ ☆ ☆

An important new book—"Investment Casting for Engineers"—has just been published by Rheinhold Publishing Co., New York. It is highly recommended reading for all design engineers.

ARWOOD

PRECISION CASTING CORP.

78 WASHINGTON STREET • BROOKLYN 1, N. Y.

Plants: Brooklyn, N. Y., Groton, Conn., Tilton, N. H.

OVER ONE HUNDRED YEARS OF CONTINUOUS SERVICE. ROUNDS, SQUARES, FLATS, HEXAGONS, OCTAGONS

MAXIMUM

TOUGHNESS • HARDNESS • STRENGTH

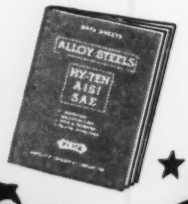
WHELCO M

OIL HARDENING TOOL STEEL

WL offers *"Whelco"* M—a tool steel of maximum toughness, hardness and strength—a steel to assure maximum results at low cost! *"Whelco"* combines great penetration of hardness, great toughness at high hardness, wide hardening range, fine grain structure, and desirable non-deforming characteristics. *"Whelco"* has good forging properties and is readily machinable in the annealed condition. All **WL** warehouses stock *"Whelco"* M tool steel in a wide variety of flats and squares. Call your nearest **WL** man for a trial order—the results will speak for themselves!

WL steels are metallurgically constant. This guarantees uniformity of chemistry, grain size, hardenability—thus eliminating costly changes in heat treating specifications.

Write today for your FREE COPY of the Wheelock, Lovejoy Data Book, indicating your title and company identification. It contains complete technical information on grades, applications, physical properties, tests, heat treating, etc.



BILLETS AND FORGINGS FOR PRODUCTION, TOOL ROOM AND MAINTENANCE REQUIREMENTS

WHEELOCK, LOVEJOY & COMPANY, INC.

Warehouse Service

CAMBRIDGE • CLEVELAND
CHICAGO • HILLSIDE, N. J.
DETROIT • BUFFALO
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In Canada
SANDERSON-NEWBOULD, LTD., MONTREAL

HY-TEN and AISI

133 Sidney St., Cambridge 39, Mass. and Cleveland • Chicago • Detroit Hillside, N. J. • Buffalo • Cincinnati

mittees in charge of the show. Exhibits have been entered by 271 firms. The exposition will be held in the Pan-Pacific auditorium and the adjacent Pan-Pacific Pavilion.

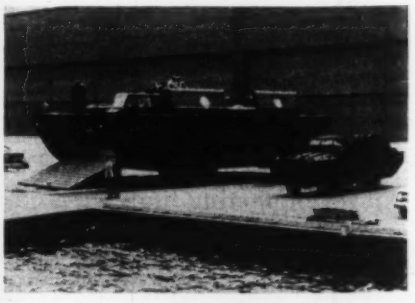
The show will feature a large display of machine tools made in Great Britain, Switzerland, Norway, Sweden, Austria, France, Italy and Japan. Lathes, boring mills, jig borers, radial drills, tool grinders, milling machines, chucks and centers will be shown in operation.

Metals, machinery, metal fabricating equipment and methods, as well as equipment for research, testing, inspection, heat treating, welding, cutting and otherwise handling metals, will be seen throughout the exposition.

Concurrent with the show, technical sessions of the Western Metal Congress will be held in Los Angeles' Statler Hotel.

Army Announces 60-Ton Amphibian

Designed to transport heavy military equipment, a huge new amphibious cargo vehicle was demonstrated recently by the Army. Designated BARC, the vehicle travels on ten-foot diameter tires and operates on principles similar to those of the DUKW of World War II. The new amphibian can transport



heavy loads from a ship in deep water, across a beach and over rough terrain to an inland supply point for direct discharge, or for transfer to truck or rail, eliminating difficult and inefficient rehandling of cargo at the waterline.

Versatility of the BARC was demonstrated by maneuvering over

obstacles, executing various turns and climbing a 45-degree slope. The vehicle has an overall length of 61 feet, width of 27½ feet, and height of 16 feet. Despite its size, it requires a single operator both on land and in the water and a basic crew of three for all operations.

Afloat, it can maneuver almost as easily as a small landing craft. Its twin screw propellers are powered by two of the four engines which drive the vehicle on land. By driving one propeller forward and the other reverse, it can spin in a relatively tight circle.

Report on Materials

Steel capacity of the United States went up 8,959,800 tons during 1952—the largest gain ever made in a year—raising the total annual capacity of this country to over 117.5 million tons, according to the American Iron and Steel Institute. This is the highest level ever achieved, and represents an increase of over 25.6 million tons in the seven postwar years.

Since 1940, the gain has been over 35.9 million tons—nearly twice the present annual capacity of Great Britain and in excess of the estimated total capacity of Russia, second largest steelmaking nation.

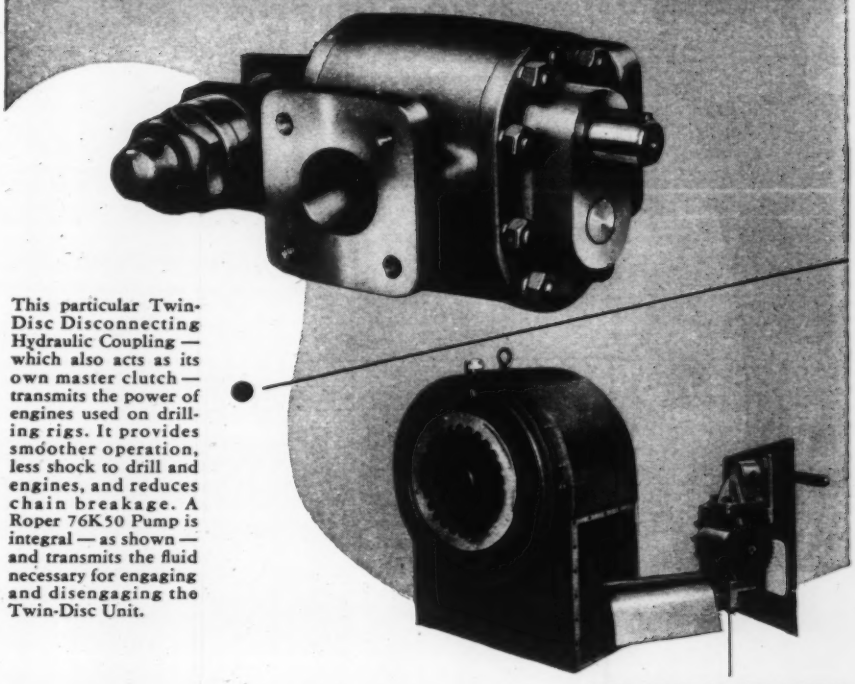
Annual steelmaking capacity is rising toward an expected figure in excess of 123 million tons of ingots and steel for castings. Present programs of expansion and improvement indicate an increase of more than 4 million tons in 1953, more than 1 million tons in 1954, and about 500,000 tons after 1954.

Supply of alloying materials is a major problem, according to the last Quarterly Report presented by Henry H. Fowler, ex-Director of the Office of Defense Mobilization. Significant gains in the levels of supply of nickel, tungsten, molybdenum and cobalt have been made since 1950, but problems of supply, stockpiling and reduction in consumption requirements still remain.

Copper in 1954: Efforts have been made since 1950 to increase the supply of copper by expanding

ROPER

works with Twin-Disc to improve efficiency of this HYDRAULIC POWER TAKE-OFF

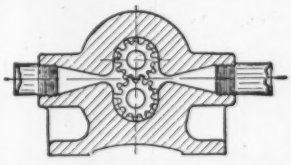


This particular Twin-Disc Disconnecting Hydraulic Coupling — which also acts as its own master clutch — transmits the power of engines used on drilling rigs. It provides smoother operation, less shock to drill and engines, and reduces chain breakage. A Roper 76K50 Pump is integral — as shown — and transmits the fluid necessary for engaging and disengaging the Twin-Disc Unit.

ROPER 76K50 PUMP

YOU CAN EXPECT DEPENDABILITY FROM ROPER

The Roper used as a vital component of this hydraulic power take-off is a special design Series K pump with built-in relief valve. In its role here, the Roper is highly regarded for its great dependability and peak efficiency under rugged conditions. Here's food for thought for you, for you might well have new equipment in process where a Roper would fill the bill. Standard Series K pumps are rated to 150 P.S.I., and delivery ranges of from 3/4 to 50 G.P.M. They are widely used for pressure lubrication, hydraulic service, transfer work, and fuel supply. Series K features (too numerous to mention here) are available to you in our latest catalog. Send for it!



VENTURI SUCTION and DISCHARGE PRINCIPLE IN SERIES K PUMPS

In Series K pumps 10 through 50. A design application whereby liquid is distributed uniformly across the gear face, increasing volumetric efficiency. Adds quietness . . . minimizes energy loss caused by turbulence, cavitation and friction.

GEO. D. ROPER CORPORATION
242 Blackhawk Park Ave., Rockford, Ill.

ROPER Rotary Pumps

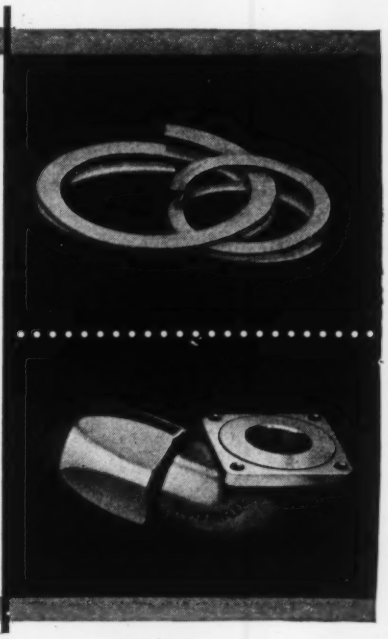
New RESISTOFLEX hose assembly . . .

withstands medium-high pressures without wire reinforcement

I.D. (inches)	Working Pressure (psi)	Min. Burst Pressure (psi)	Assembly Tensile Strength (lbs.)
¼	2300	9200	900
⅜	2050	8200	2500
½	1800	7200	3500

Synthetic fibre-braid carcass and non-aging compar tube in Resistoflex hose provide strength for medium-high pressure hydraulic systems without need for metal reinforcements. This assures flexibility with extreme resistance to fatigue. These hose assemblies have high pull strength and long hydraulic impulse life. The compar tube also assures freedom from swelling and gumming due to hydraulic oils, and full flow through fittings.

TEFLON® SPIRAL BACK-UP RINGS
Made from uniform "Fluoroflex-T"* tubing — stress relieved before machining for dimensional stability of rings. These anti-extrusion rings withstand −100°F to +500°F. Self lubricating, they eliminate abrasion on "O" rings, reduce friction of the assembly. Chemically inert and non-fraying, they cause no malfunctioning of other hydraulic system components.



AIRCRAFT HOSE ASSEMBLIES
"AN" types which conform in every particular to military specifications. All sizes, for hydraulic, pneumatic and vacuum lines, as well as fuel, gas and oil lines. Assemblies with Resistoflex forged aluminum, compact, flanged, elbow fittings carry USAF and BuAER approvals. Send for AIRCRAFT CATALOG with full specification details.

RESISTOFLEX
CORPORATION
Belleville 9, New Jersey

* *Resistoflex trade mark for products from fluorocarbon resins.*

Engineering News

production from domestic ore and increasing exports. But significant increases in supply cannot be expected before 1954, according to the same source.

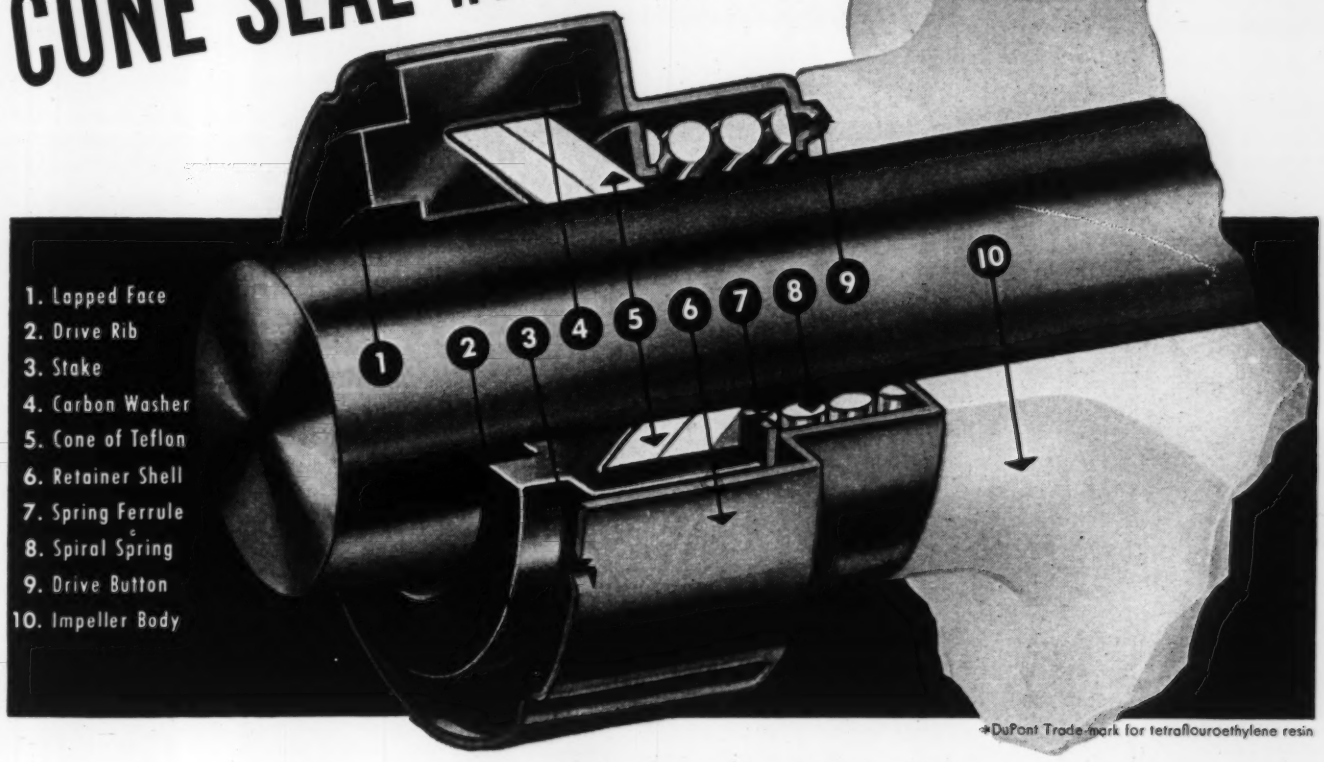
The acute copper shortage might be relieved in 1953, says J. J. Russell, chairman of the board of Revere Copper and Brass Inc., if current pricing difficulties on scrap copper can be overcome through decontrol. Like Mr. Fowler, Mr. Russell sees no great relief until new mines start producing in 1954. However, release of pent-up scrap copper, perhaps as much as 150,000 tons, could be effected by termination of the present multiple pricing system in the refined copper market, according to Mr. Russell. This would amount to an increase of about 10 per cent in the domestic supply of refined copper.

"Open" CMP in 1953: It may be possible to "open-end" the Controlled Materials Plan in the first half of 1953, says the Quarterly Report, and allotments of most shapes and forms of controlled materials may permit restriction of allotments to direct military, stockpile and atomic-energy programs later in 1953.

Steel is no problem, and as supplies increase the "open-ending" should proceed rather smoothly. Production capacity and total supply of copper have both increased, but the water shortage in the Pacific Northwest, which is expected to last at least through the present quarter, may slow things up a bit. The outlook for copper in 1953 is slightly less favorable, however, since total military and AEC requirements will be larger in 1953 than in 1952. Total amount of copper available for all other uses will probably be no greater than in 1952.

Low-Cost Cold Rubber: A new process that produces "cold" rubber 50 times faster than current methods "apparently offers unlimited opportunity for the production of improved rubbers at lower costs," according to J. L. Collyer, president of the B. F. Goodrich Co. Still in the pilot-plant stage, the new method produces high-quality

BRAND NEW CONE SEAL with TEFLON*



*DuPont Trade-mark for tetraflouroethylene resin

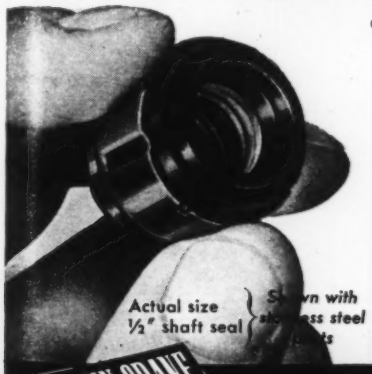
The All-Purpose Seal

For life-time performance in small pumps, hot water circulators and many other rotary shaft seal applications

Temp. −100° F. to +450° F. WATER-OILS-ACIDS PRESSURES 200 PSI

ADVANTAGES •• "JOHN CRANE" TYPE 19 CONE SEAL WITH TEFLON

1. Cones of Teflon will not deteriorate under −100° F. or +450° F.
2. Cones of Teflon are not attacked by any acid.
3. Cones of Teflon seal tight on shaft and in carbon washer, low pressure or high pressure.
4. Cones of Teflon stay put and have long life.
5. Type 19 Sealing Unit (with Teflon) has all the requirements of a good seal: positive drive, axial and radial movement, free sliding flexible spring action to compensate for wear of carbon washer, ease of application and replacement, long life, compactness.
6. Type 19 Sealing Unit (with Teflon) is a packaged seal, presently designed for small shafts ¼, ⅜, ½, ⅝, ¾" dia.
7. Type 19 Sealing Unit (with Teflon) is tooled for the high production field. It has a wide field of application.
8. Type 19 Sealing Unit (with Teflon) can be manufactured at an economical price.
9. Type 19 Sealing Unit (with Teflon) is manufactured in the "pressed-in" type where seal unit is held stationary.



SPECIAL NOTE

Teflon is the answer to the automotive and aircraft engineer's specification for an extremely low and high temperature range. It is fast replacing rubber parts which have a tendency to harden, crack, soften, or otherwise fail.

In the early stages of any seal application we might be helpful. For instance—the metallurgy of a seal is important; you may have space limitations or you may have r.p.m. problems. These are only a few points. Drop us a line.

Crane Packing Company, Dept. MD 1825 Cuyler Avenue, Chicago 13, Illinois.

JOHN CRANE

CRANE PACKING COMPANY

CANNON PLUG ACCESSORIES

for the "AN" Series

Here is the answer to a frequent question we receive from people everywhere. Yes, Cannon *does* make a complete line of accessories to be used in conjunction with the AN Series of connectors. Complete engineering data on each of these is given in the Cannon AN Bulletin, available on request.

CANNON ELECTRIC

Since 1915

Factories in Los Angeles, Toronto, New Haven, Benton Harbor. Representatives in principal cities. Address inquiries to Cannon Electric Company, Dept. B-185, P. O. Box 75, Lincoln Heights Station, Los Angeles 31, California.

cold rubber in 15 to 20 minutes as compared to 10 to 12 hours now required with present production methods.

Like present cold rubbers, the material made by the new process has a tensile strength 25 per cent higher than the GR-S general-purpose rubber made during World War II, according to Collyer, and is tougher. The process cannot be used, however, in existing plants for manufacturing man-made rubber.

Basic Materials and Alternates: In the latest *List of Basic Materials and Alternates,* very little change in metals is reflected, except for a slight easing among the ferroalloys. Released December 29th, the list shows a continued easing among chemicals and plastics but at a slower rate than previously. Aluminum continues to be listed in Group II although a strict interpretation of classification definitions would place the metal in Group I; the present aluminum situation is considered to be temporary.

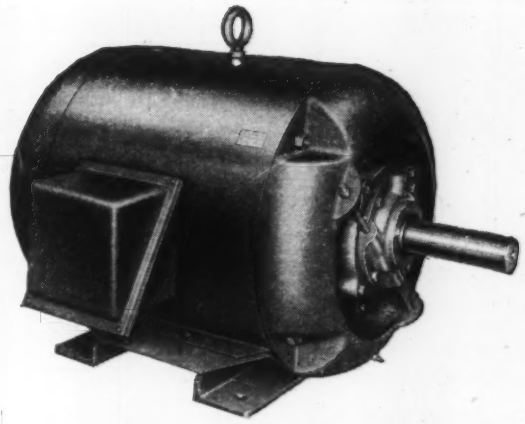
Metals—Group I-A
(In short supply)

a—Nonferrous:
- Beryllium
- Selenium (all grades)
- *Titanium

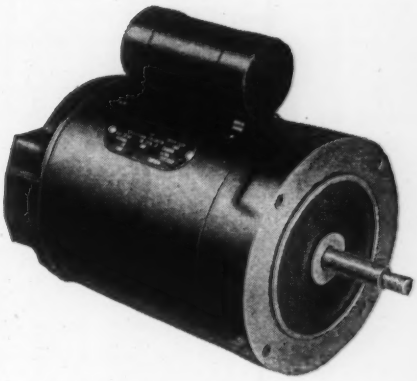
b—Precious:
- Platinum

c—Ferrous alloying elements:
- *Cobalt
- *Columbium
- Manganese (electrolytic metal)
- *Molybdenum
- *Nickel
- *Tantalum

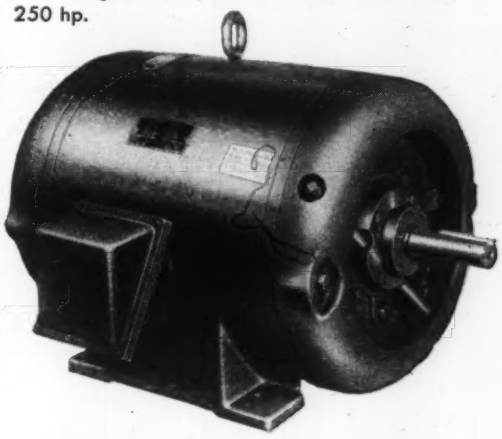
d—Ferrous:
- Bars, cold drawn:
  - Alloy
  - Carbon steel
- Bars and semi-finished, hot-rolled:
  - Alloy
  - Carbon steel
- Castings:
  - *Gray iron: Heavy, over 3000 pounds
  - *Gray iron alloy: Heavy over 3000 pounds
  - *Carbon steel: Heavy, over 3000 pounds
  - High alloy steel:
  - Corrosion-resistant
  - Heat-resistant
- Castings:
  - Low alloy steel: Heavy over 3000 pounds
- Forgings, heavy, over 10,000 lb
- Iron powder
- Pig iron, low phosphorus
- Pipe:
  - Seamless, all sizes
  - Welded: 4 inches and over
- Plates
- Rails
- Shapes, structural
- Sheet:
  - Cold rolled
  - Galvanized
  - Hot rolled
- Strip:
  - Cold rolled
  - Hot rolled
- *Stainless steel: Nickel bearing
- Strandwire, galvanized
- Tubing, seamless:
  - Alloy, mechanical
  - Alloy pressure
  - Carbon, mechanical
  - Carbon, pressure



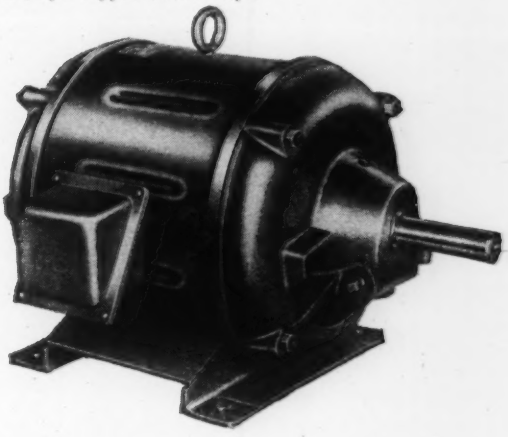
Type CP—Totally-enclosed Fan-cooled. Protected against dirt, fumes or moisture. 1 to 250 hp.



Jet Pump Motors—Single phase, capacitor-start, open type. ¼ to 1 hp.



Type EP—Corrosion-resistant cast iron. Totally-enclosed Fan-cooled. 2 to 250 hp.



Type RP—Open type, sleeve bearing, polyphase squirrel cage. 1/6 to 400 hp.

furnish plenty of power for pumps...

Improve the performance, economy and dependability of your product by choosing Wagner Motors. Bulletin MU-185 gives information on the complete line. Let a Wagner engineer discuss your motor needs with you. Consult the nearest of our 32 branch offices, or write us.

it's to your advantage to standardize with Wagner:

When you standardize on Wagner Motors—you get the advantages of a liberal warranty . . . of nationwide service facilities, with on-the-spot service, replacement motors and parts available from 25 Wagner-owned Service Branches and more than 750 Authorized Service Stations. You can choose from a wide variety of types and sizes (from 1/125 to 400 hp).

WAGNER ELECTRIC CORPORATION
6404 Plymouth Avenue • St. Louis 14, Mo., U. S. A.

®Wagner Electric Corporation EST. 1891

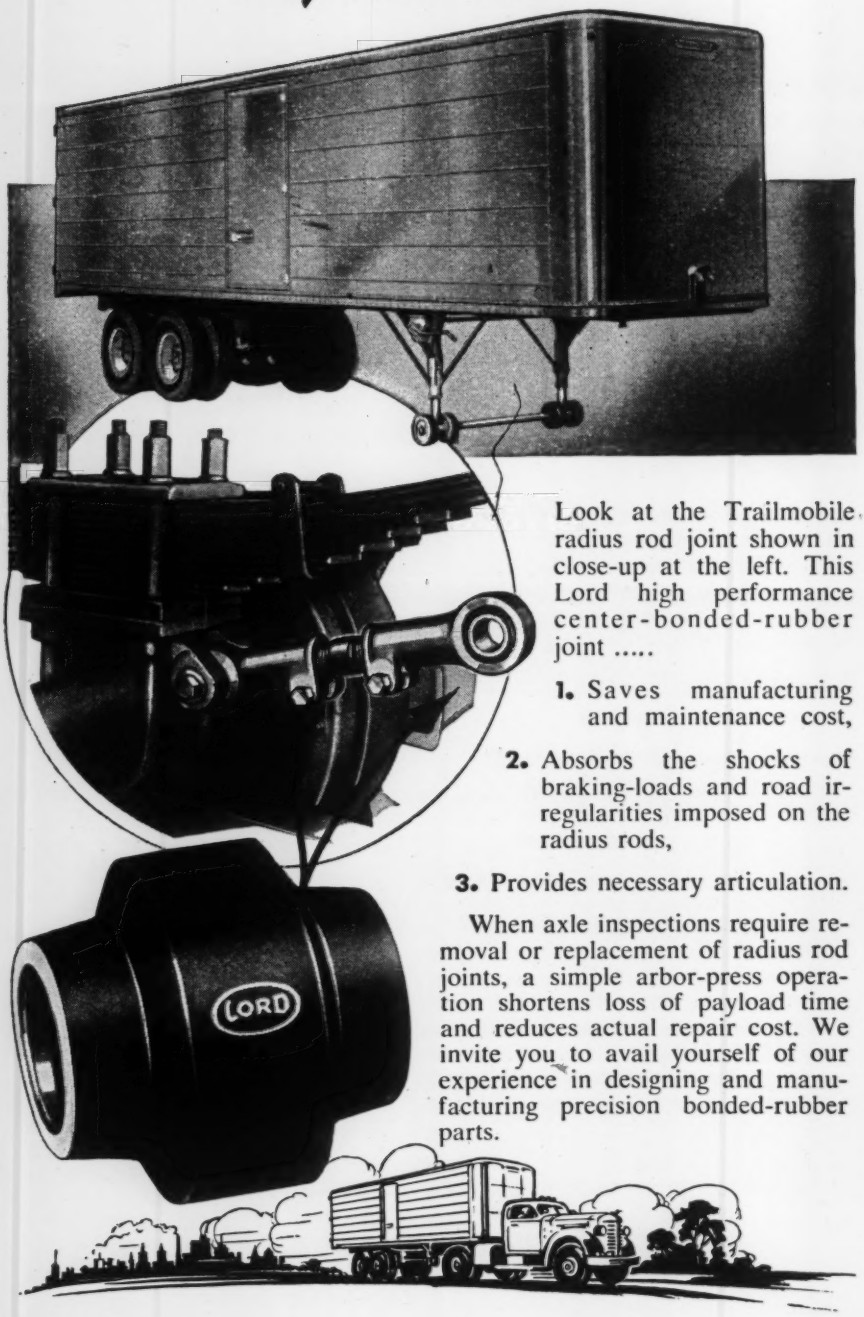
ELECTRIC MOTORS • TRANSFORMERS • INDUSTRIAL BRAKES
AUTOMOTIVE BRAKE SYSTEMS—AIR AND HYDRAULIC

BRANCHES IN 32 PRINCIPAL CITIES

M53-1

TRAILMOBILE

RADIUS ROD JOINTS by LORD



Look at the Trailmobile radius rod joint shown in close-up at the left. This Lord high performance center-bonded-rubber joint .....

1. Saves manufacturing and maintenance cost,
2. Absorbs the shocks of braking-loads and road irregularities imposed on the radius rods,
3. Provides necessary articulation.

When axle inspections require removal or replacement of radius rod joints, a simple arbor-press operation shortens loss of payload time and reduces actual repair cost. We invite you to avail yourself of our experience in designing and manufacturing precision bonded-rubber parts.

BURBANK, CALIFORNIA 233 South Third Street
DALLAS, TEXAS 413 Fidelity Union Life Building
PHILADELPHIA 7, PENNSYLVANIA 725 Widener Building
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LORD MANUFACTURING COMPANY • ERIE, PA.

LORD BONDED RUBBER

Headquarters for VIBRATION CONTROL

Engineering News

Miscellaneous—Group II-D
(In approximate balance)

Graphite, natural:
- Crucible flake
- Ceylon: High carbon amorphous lump

Mica:
- Muscovite block (stained)

Quartz crystals (MBS Grades I and II)

Rare earths

Refractories:
- Chromite
- Silicon carbide

Miscellaneous—Group III-D
(In fair to good supply)

Asbestos, Chrysotile: Shorts and waste fibers

Graphite, artificial: Electrodes, anodes and special shapes

Mica:
- Muscovite block (heavy stained)
- Phlogopite, splittings

Refractories:
- Dolomite
- Fire clay
- High alumina
- Magnesite
- Silica
- Sillimanite

Rubber:
- Butyl (GRI)
- Synthetic (GRS)
  - Cold

Talc:
- Ground, including steatite
- Indian block, lava grade

A comparison between the listings of December 1951 and 1952 shows an interesting change in the total number carried and in distribution. In 1951, 456 items were carried; in the latest issue, only 323. In addition, the distribution has shown a corresponding shift:

Year	Most Critical (%)	Group I (%)	Group II (%)	Group III (%)
1951	6	29	34	31
1952	3	24	32	41

Many significant changes occurred in the listings during the year. Lead and zinc went from "most critical" to Group III in June, and copper, aluminum and tin went from "most critical" to Group II in August. Among the others removed from the "most critical" category were cold-drawn and hot-rolled alloy steel bars, heat-resistant alloy steel castings, plates, structural shapes, beryllium, selenium, platinum, and tungsten.

Chemicals have shown the most consistent improvement in supply, with 87 completely removed from the list between May and December. In the miscellaneous category, 27 materials were removed from Groups II and III in the latest issue.

Complete copies, from which the foregoing listing is abstracted, may be obtained on request from Printing Services, Department of Commerce, Washington 25, D. C., or any district or regional office of the Commerce Department.

Stress Relief

AT A TIME when many plants were taking year-end inventory, one engineer we know decided that perhaps a tally of engineering department affairs would be in order. John Eggert of Bethlehem's Lackawanna Plant writes that in the following tally sheet he's putting the finger on . . . "some of the most prominent weaknesses I have encountered working in engineering departments in New York, Alabama, Florida and texas. (The lower case 't' in texas is intentional.)"

Engineering Department Tally

Will your company's position in the competition of tomorrow depend upon the engineering you are doing today? If so, let's take stock.

Engineering: If a good engineer saves more than his salary, why not make money with the whole engineering department?

Does the accounting system show the profit or loss due to the engineering department? This information should take the department out of the lumped over-head class and can be a useful wedge to obtain better equipment and higher salaries.

Do cost estimates vary widely from actual production costs? This sometimes serves a purpose, but if it doesn't, how long is it since an up-to-date list of manufacturing costs was issued?

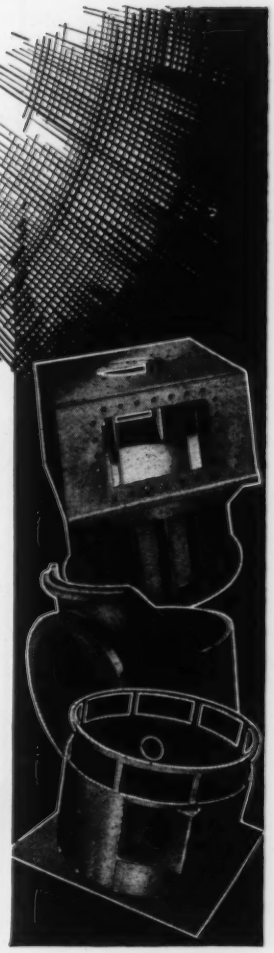
Are design or layout decisions made on the basis of more than one independently prepared designs, or do you use the hit-or-miss one man's opinion system?

Are features of design incorporated solely because, "That's the way we always do it?"

What percentage of engineering time is spent on clerical work?

Was the indexing system established by the office boy in 1910? If so, can you estimate how many companies are in business selling

Weldments
BY LITTLEFORD
INSURE PRODUCTION
ECONOMY & QUALITY



Littleford Weldments have four basic advantages:

1. MODERN DESIGN—Welded metal fabrication lends itself to efficient modern design, shaping metal on modern equipment is a simple task.
2. LESS WEIGHT AND BULK—Unwieldy and needless weight are eliminated in Weldments.
3. STURDY—Weldments have inherent strength, toughness to withstand shock, strain and vibration.
4. ADAPTABILITY—Weldments adapt themselves to changes and improvements at any time with minimum of cost.

Littleford complete fabricating service and 70 years experience in laying out, forming, shearing and welding all types of metals is assurance of quality weldments regardless of size. Write for Weldment Bulletin.

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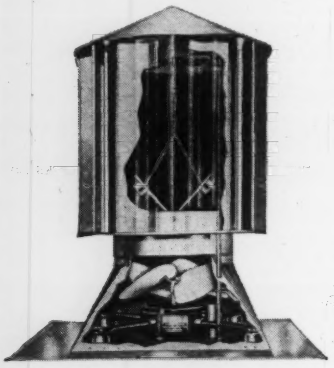
FILLING AN INDUSTRIAL ORDER. Craftsman starting to "spindown" stainless steel guard bowl for laboratory centrifuge unit. An example of the all-gage — all-metal — any quantity — spinning capacity available at Teiner. *Write for newest color brochure 52D*

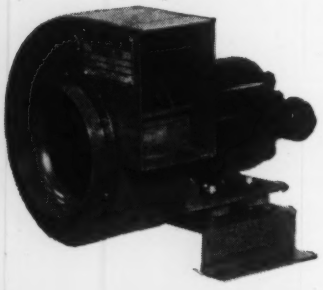
ROLAND TEINER CO. INC. · EVERETT · MASSACHUSETTS ·
ROLAND TEINER
CO. INC. 134 TREMONT ST., EVERETT 49, MASS.

SHOCK AND VIBRATION NEWS

Exhaust Fans Quieted by Vibration Isolators



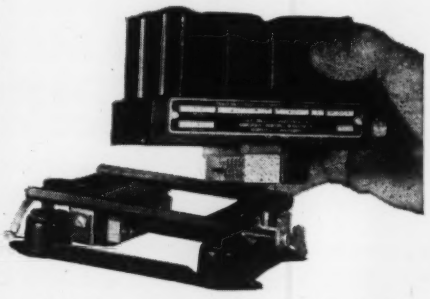
The problem of motor and fan noise is successfully overcome in the Breidert Air-X-Hauster by use of four air-damped Barrymounts that support the low-speed motor and fan assembly. These isolators absorb the motor and fan vibration, keeping it from reaching building members or metal ducts along which it would otherwise be carried or amplified. To assure adequate isolation, the mountings used were type 990 Barrymounts having a natural frequency of only 8 cps.



Another example of use for Barrymounts in ventilating systems is with the high-speed Westinghouse-Sturtevant multi-vane, railway car fan. Here they isolate fan vibration for quieter operation and protect the assembly from the shocks incidental to mobile service. In this application, type C-2000 Barrymounts were used to provide protection against forces applied laterally as well as vertically.

Your vibration or noise problem may be solved by a simple application of Barrymounts. Ask our Field Engineering Department; they'll gladly help you. Or write for Catalog 504-B, describing Barrymounts for a wide variety of uses.

Miniaturized Vibration Isolators Help Cut Space and Weight in Fuel-Gauge Power Unit



70% size reduction and 50% weight reduction — with no loss of performance — is the effective miniaturization obtained in the new Minneapolis-Honeywell aircraft-fuel-gauge power unit. Miniature, air-damped Barrymounts, Type 6465, helped M-H engineers in this achievement.

These vibration isolators, in which size and weight have been cut while operating characteristics have been maintained, will help you redesign for miniaturization.

Check these useful features of miniaturized Barrymounts.

Light weight — only 5/16 ounce each.

Small size — 1" diameter 11/32" loaded height.

Resonant frequency — 9 cps

Transmissibility at resonance — 3

Wide load range — 0.1-3 pounds

4 different styles available — for plate or stand-off mounting.

Write for data sheets 605 and 606 giving details of dimensions and load ratings.

FREE CATALOGS

- 523-A — Air-damped Barrymounts for aircraft service; also mounting bases and instrument mountings.
- 509-A — ALL-METL Barrymounts and mounting bases for unusual airborne applications.
- 504-B — Shock mounts and vibration isolators for marine, mobile, and industrial uses.
- 607 — How to cut maintenance costs by using Barrymounts with punch presses.

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What pieces are detailed on the drawing that might better be furnished in stock size and cut to fit in the field?

What items are continually detailed that could be rubber stamped and the dimensions added?

Are standard fastening methods detailed, or merely coded?

Have company standard parts been brought up to date and are they merely referenced on the drawing, or are such parts detailed day after day?

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Are drawings made on such a scale that they resemble fine etchings, because of the delusion that savings in paper and printing are significant?

Are drawing sizes standardized?

Is a list of preferred stock sizes maintained or do you prefer to design for stock that must be ordered special?

Have the physical properties of the materials used been standardized, or does each man use his own handbook values?

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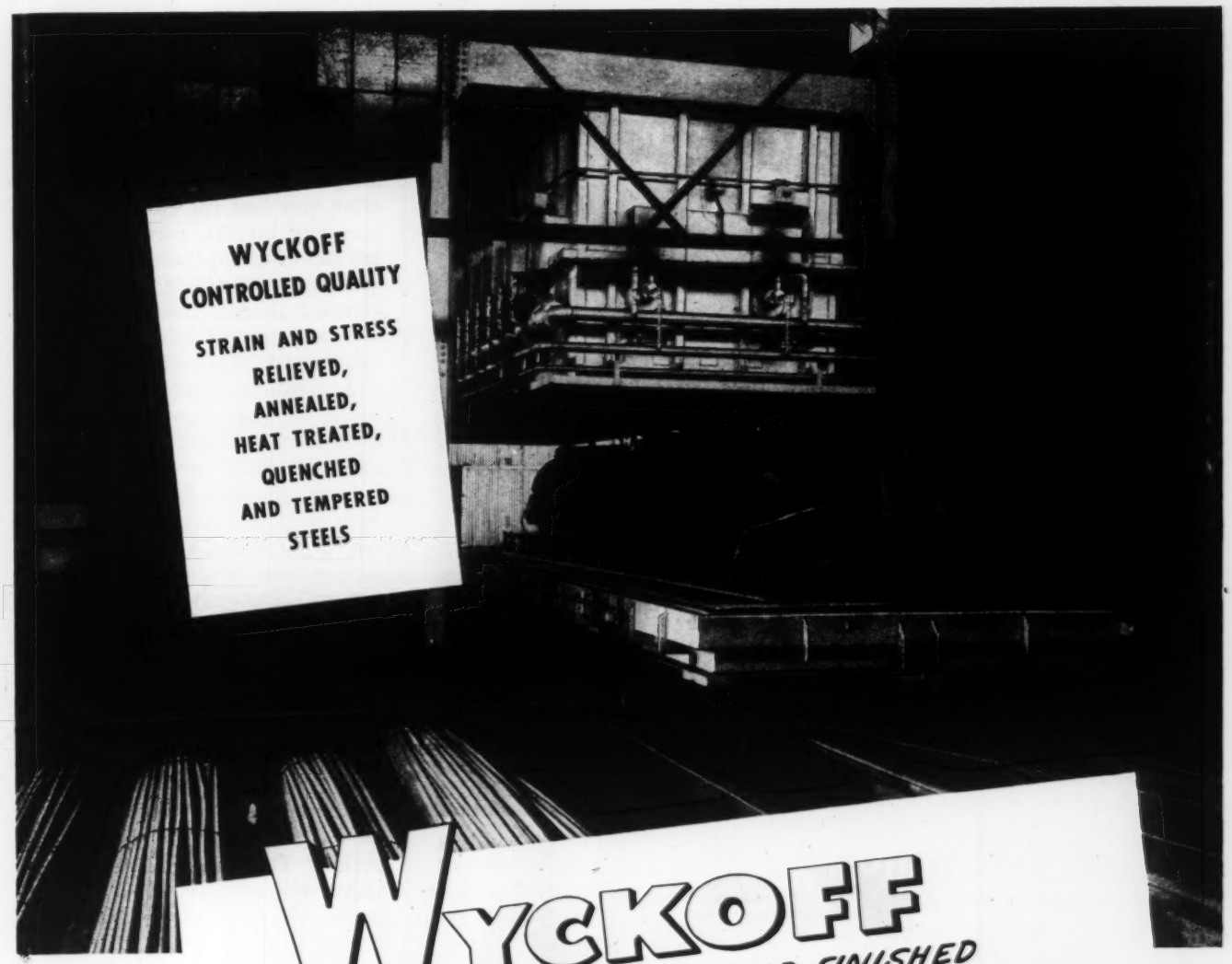
Are many hours spent on graphs and charts which might better be prepared from one master blank framed under glass and the information shown with colored cellulose tape?

Do salesmen wander around taking up everyone's time, or is a room set aside where the two or three men concerned can get the information simultaneously?

Clerical Work: Modern equipment catalogs are works of art,



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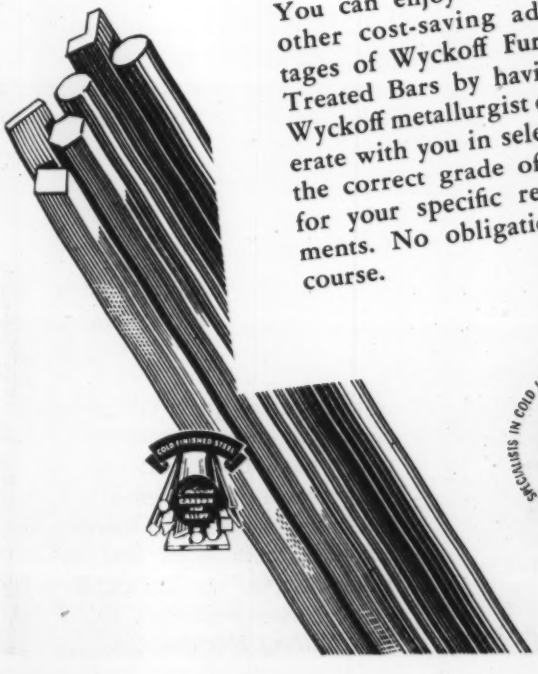

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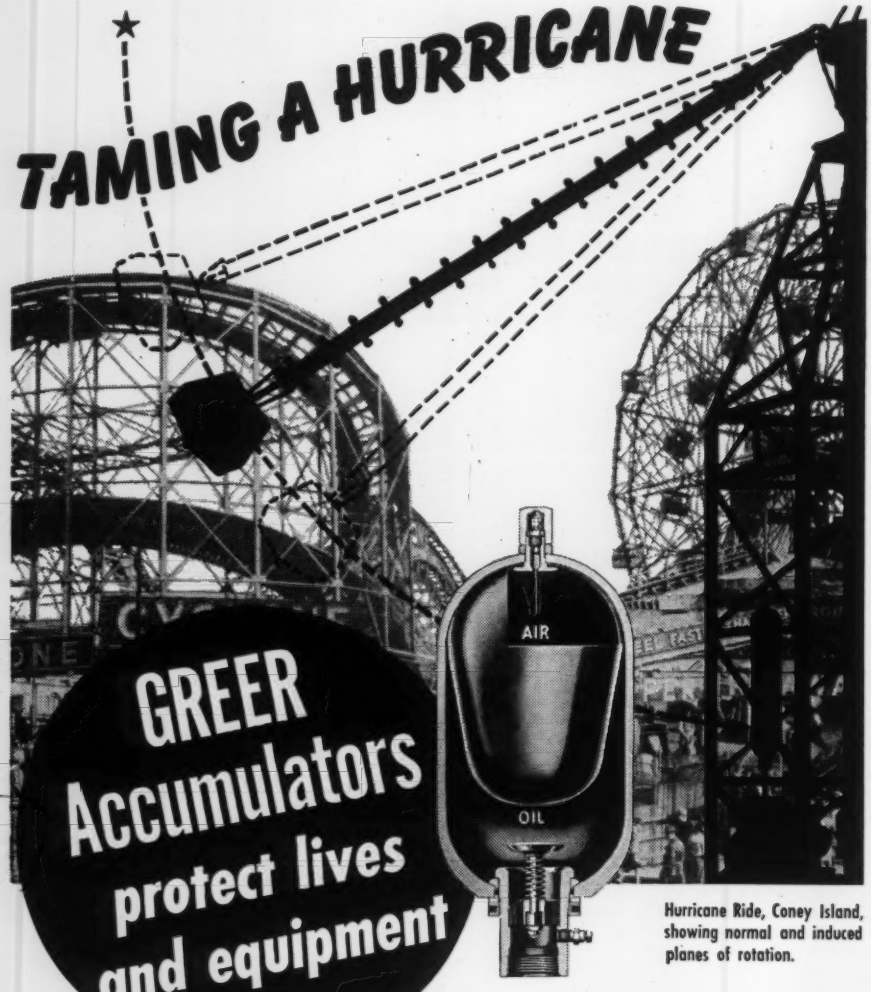

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   c. Emergency power source.
2. PRESSURE-VOLUME COMPENSATOR for
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   b. Temperature compensation.
3. DISPENSER OF FLUIDS and Lubricants.
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Meetings

AND EXPOSITIONS

Feb. 16-18—

American Management Association. Personnel conference to be held at the Palmer House, Chicago, Ill. Additional information may be obtained from society headquarters, 330 West 42nd St., New York, N. Y.

February 18-20—

Society of Plastics Industry. Eighth annual reinforced plastics division conference to be held at the Shoreham Hotel, Washington, D. C. Additional information may be obtained from society headquarters, 67 West 44th St., New York 18, N. Y.

Mar. 2-6—

American Society for Testing Materials. Spring meeting to be held at the Statler Hotel, Detroit, Mich. Additional information may be obtained from society headquarters, 1916 Race St., Philadelphia 3, Pa.

Mar. 3-5—

Society of Automotive Engineers. Passenger car, body and materials meeting to be held at the Sheraton-Cadillac Hotel, Detroit, Mich. Additional information may be obtained from society headquarters, 29 West 39th St., New York 18, N. Y.

Mar. 8-11—

American Institute of Chemical Engineers. Annual spring meeting to be held at Hotel Buena Vista, Biloxi, Miss. Stephen L. Tyler, 120 East 41st St., New York 17, N. Y., is secretary.

Mar. 9-12—

National Electrical Manufacturers Association. Midwinter convention to be held at the Edgewater Beach Hotel, Chicago, Ill. Additional information may be obtained

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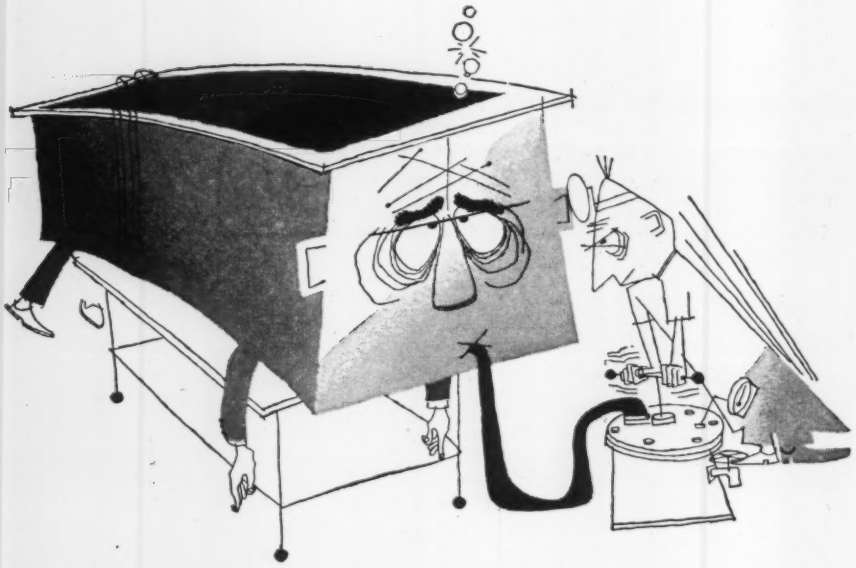

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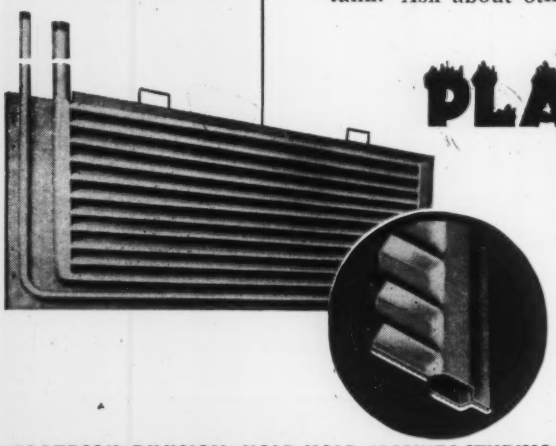

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Meetings and Expositions

from society headquarters, 155 East 44th St., New York 17, N. Y.

Mar. 16-20—

National Association of Corrosion Engineers. Annual conference to be held at Hotel Sherman, Chicago, Ill. A. B. Campbell, 919 Milam Bldg., Houston 2, Texas, is secretary.

Mar. 17-18—

Steel Founders' Society. Annual meeting to be held at the Edgewater Beach Hotel, Chicago, Ill. Additional information may be obtained from society headquarters, 920 Midland Bldg., Cleveland, O.

Mar. 18-20—

American Society of Tool Engineers. Annual meeting to be held at Hotel Statler, Detroit, Mich. Harry E. Conrad, 10700 Puritan Ave., Detroit 21, Mich., is executive secretary.

Mar. 23-27—

American Society for Metals. Eighth western metal exposition to be held at the Pan-Pacific Auditorium, Los Angeles, Calif. concurrently with the Western Metal Congress which is to be held at the Statler Hotel, Los Angeles, Calif. Additional information may be obtained from exposition headquarters, 7619 Beverly Blvd., Los Angeles, Calif.

Mar. 25-27—

Society of Automotive Engineers. First national production meeting to be held at the Hotel Statler, Cleveland, O. Additional information may be obtained from society headquarters, 29 West 39th St., New York 18, N. Y.

Mar. 31-Apr. 2—

International Magnesium Exposition to be held at National Guard Armory, Washington, D. C. Calvin H. Corey, 261 Constitution Ave., Washington 1, D. C., is general chairman.

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I'M OSBEAR

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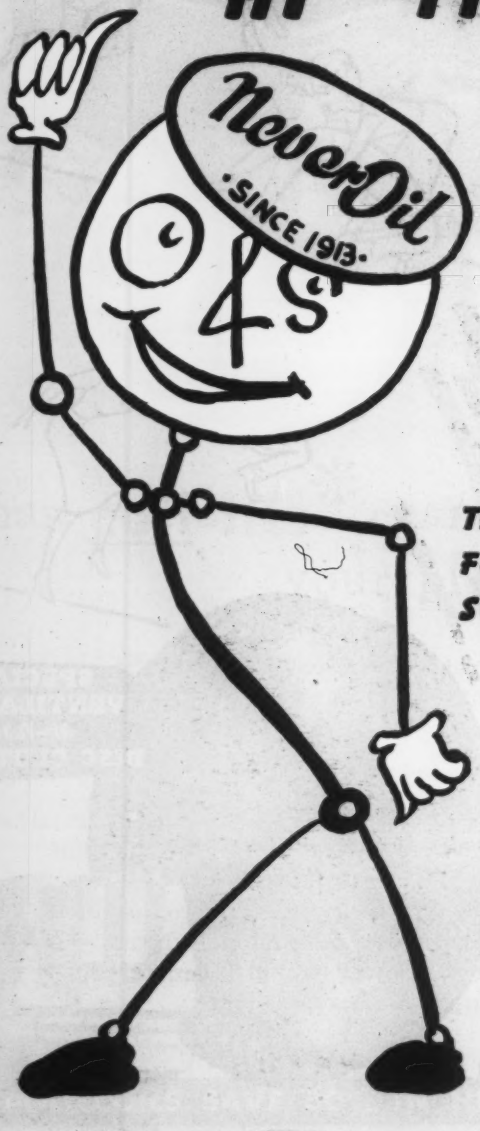

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Remember—on those difficult bearing problems you can't beat a Lubrikon and I'm Osbear—King of all Lubrikons.

I'm number one choice wherever anyone needs a non-metallic, self-lubricating bearing for a spot difficult or impossible to lubricate.

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Design Abstracts

(*Continued from Page* 187)

ment, it follows that r will change when the stroke length is changed. The ratio r increases as the stroke length decreases, since the internal volume remains the same while the plunger displacement decreases.

Fluid-powered controlled-volume pumps have a definite advantage over motor-driven units in regard to stroke length adjustment and its effect on volumetric efficiency. Stroke length adjustment is made around the center of the crank on motor-driven pumps while adjustment by limiting the return stroke of the plunger is used on fluid-powered pumps. Using C as the displaceable volume in any liquid end and D as the displacement of the plunger on maximum stroke length, the ratio r equals $(C + D)/D$. Decreasing the stroke length to half its maximum, the ratio r for a fluid-powered pump equals $(C+D/2)/(D/2)$. When the stroke length is reduced to half its maximum on motor-driven pumps C is further increased by $D/4$ because the plunger does not return to the same forward position. This increase in C on motor-driven pumps further increases the ratio r which in turn further decreases the volumetric efficiency. A comparison of the two illustrates the definite advantage of the fluid-powered controlled-volume pumps in this respect.

Safety and New Development: Use of controlled-volume pumps in high pressure service has been proved safe as those for lower pressures by using certain precautions. High-pressure tubing specifically designed for the operating range is required. A positive relief valve is installed on the discharge side of the liquid end to protect the pump and system from overpressure due to accidental blocking or closure in the discharge line. The relief valve is piped to a safe point of discharge, possibly back to the suction side of the pump, and the pipe employed must be of sufficient size to permit quick discharge and relief of the pressure.

Fluid-powered pumps are pro-

School Daze!

Just because that bathing suit is proper at the beach, she shouldn't assume it's proper for the classroom, too!

And just because one bearing is best lubricated by one particular grade of oil, you shouldn't assume that the same oil is best for *all* bearings on that machine. In many cases it isn't.

OIL CUPS permit you to lubricate each bearing with the oil best suited to that bearing—thus prolonging bearing life, reducing maintenance costs, cutting down-time, boosting production. And oil cups fortunately *cost very little.*

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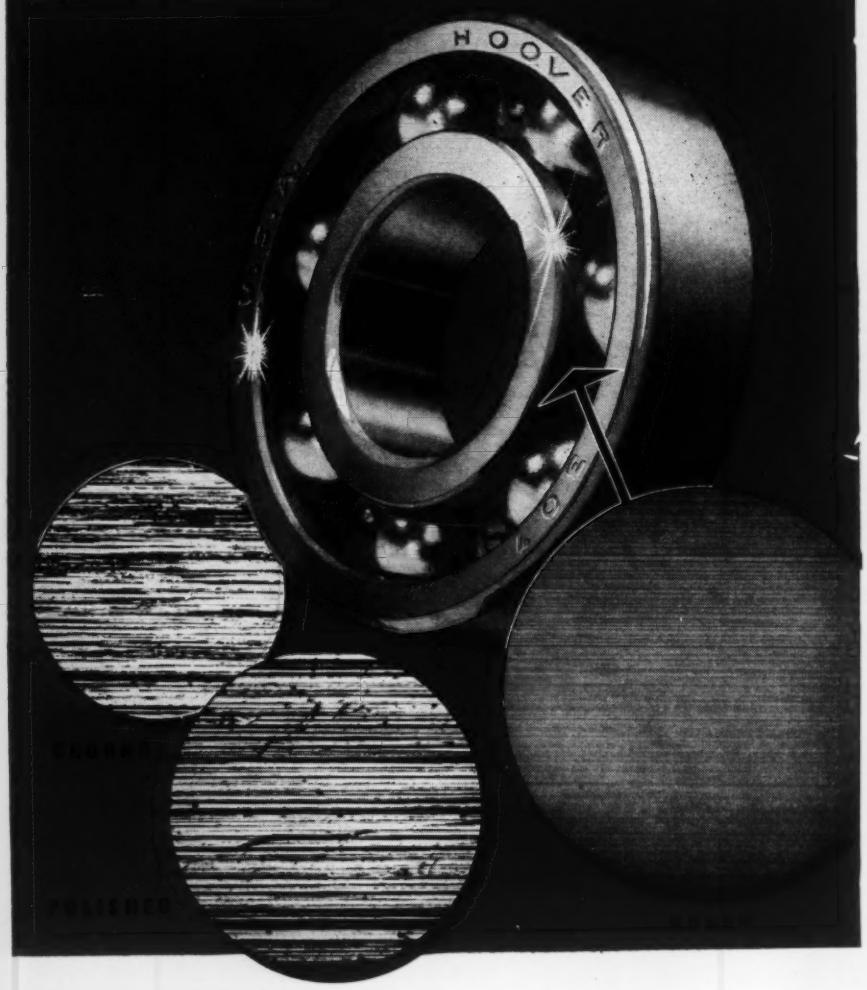

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The photographs reproduced above are magnified one hundred times so you can see the difference between ground, polished and honed raceways. The process and the special machines for the honing operation are exclusive, patented, Hoover developments. Honing by Hoover goes far beyond grinding and polishing to achieve a surface that assures amazing quietness plus *90 per cent longer bearing life . . . 30 per cent greater load capacity.* That's why Hoover Ball Bearings are the choice of distinguished American manufacturers of fine machines and equipment.

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tected by placing a relief valve in the fluid pressure line, since limiting the fluid pressure automatically limits the discharge pressure against which the pump can operate. High-pressure liquid ends should be given hydrostatic tests, initially by the manufacturer and then periodically by the user.

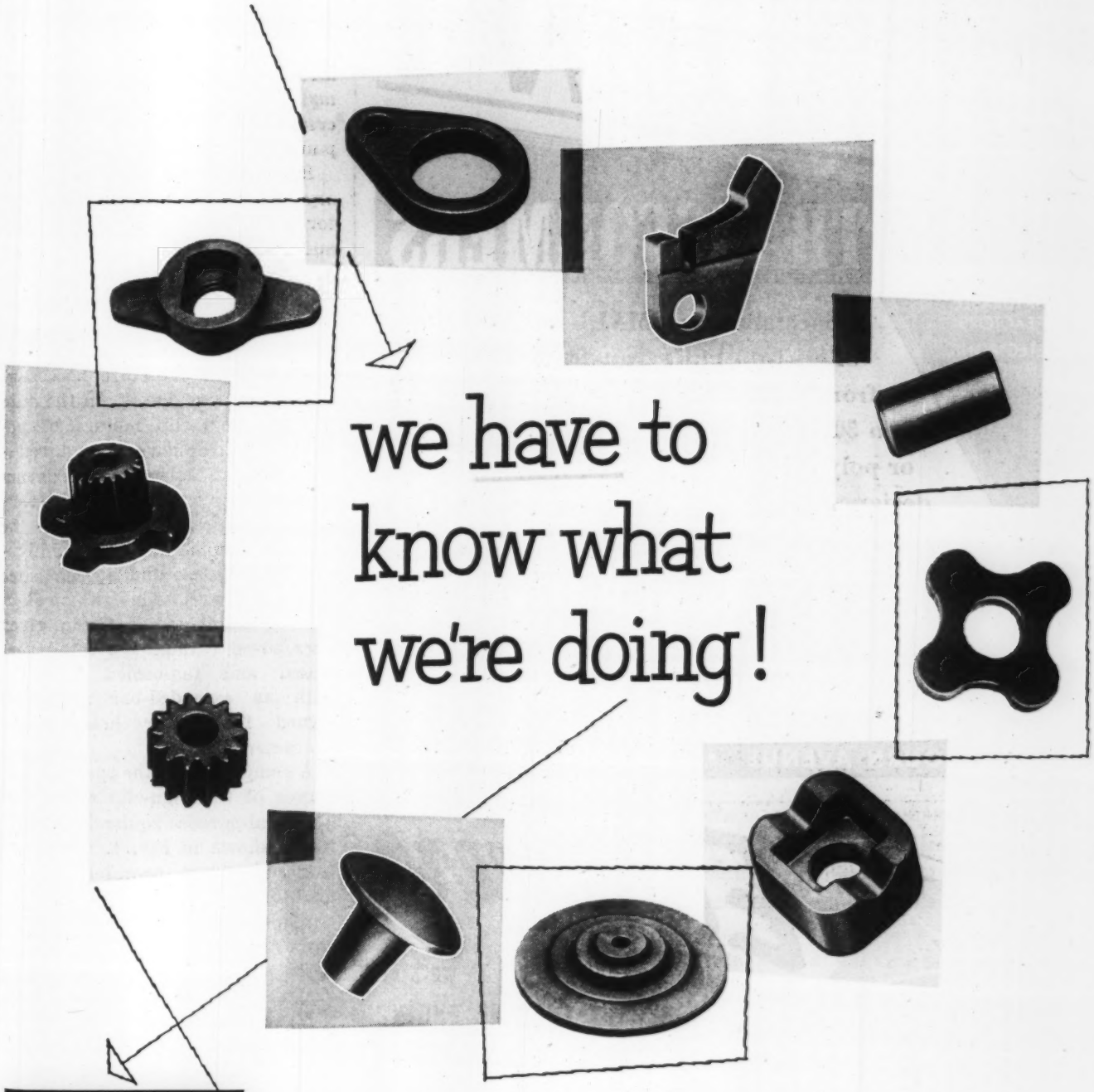
Even with these precautions, some users place pumps behind heavy barriers for protection of the operators, although this is usually due to the explosive nature of the materials handled rather than the high pressure itself. However, caution must always be exercised, for there are some phenomena experienced at high pressure which are not clearly understood at this time. The explosive decomposition of propylene, ethylene, and acetylene is an example. Under certain pressure-temperature conditions these may decompose spontaneously with a sudden violent rise in pressure and temperature. The use of jacketed liquid ends is desirable on many applications where it is essential to limit temperature rise.

From a paper entitled, "Design and Application of Controlled-Volume Pumps for High-Pressure in the Range of 10,000 *to* 30,000 *psi" presented by the ASME Industrial Instruments and Regulators Division at the Seventh National Instrument Conference in Cleveland, O., September,* 1952.

High-Slip Motor

By R. Y. Newton
Design Engineer
Small and Medium Motor Dept.
General Electric Co.
Schenectady, N. Y.

THE PUNCH press that forms the smooth, flowing, and vulnerable lines of the automobile imposes a distinctive type of loading on its drive-motor. A large flywheel, used to give the tremendous punching power economically, stores rotational energy between strokes. To deliver the energy the flywheel must slow down during the punching operation. Otherwise the instantaneous energy required would stall the motor. The drive-



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For more than a quarter of a century we've been successfully making metal powder parts . . . *billions* of them . . . because we have that vital commodity—a combination of knowledge and experience called *know-how*.

Our metal powder parts are doing more and better jobs for industry every day and we offer our customers an ever widening choice of materials for ever broader applications. Moraine parts have close tolerances, improved physical properties, and are produced in ever more complicated designs.

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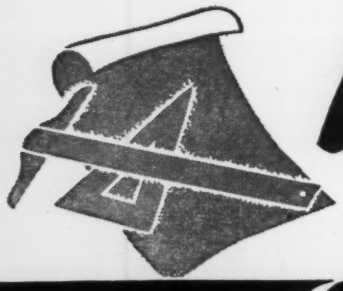
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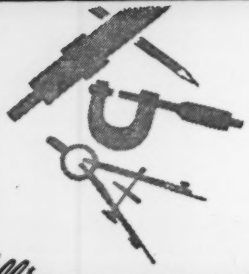
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motor speed must therefore normally decrease with the sudden increase in torque caused by the punching operation.

But here's the hitch—an ordinary general-purpose induction motor won't slow down appreciably under an increased load. Its rotor doesn't slip but maintains a fairly constant speed until the breakdown value of torque is reached.

A special type of motor, the high-slip motor, is therefore necessary for punch-press drives. In the auto industry high-slip motors of enclosed construction are required—and such a design using conventional motor construction is very difficult. Recently introduced, the extended-bar motor meets the high-slip requirement and at the same time makes possible a smaller, more efficient motor for a given horsepower rating. It's totally enclosed and fan-cooled (TEFC), with an extended-bar rotor designed for better heat-transfer characteristics.

A comparison of the speed-torque curves of the high-slip motor and a general-purpose squirrel-cage motor is shown in *Fig.* 1. As a further comparison, consider the full-load torque and the slip speed (synchronous speed minus running speed) of the two.

The high-slip motor is usually designed for a starting torque of 275 per cent of full-load torque and a slip speed of 5 to 13 per cent, depending on the application. Slip at full load is an indication of how much the motor will slow down with increased load.

On the other hand, the general-purpose motor (in sizes 5 to 100

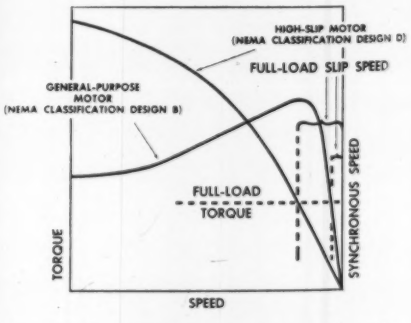

Fig. 1—Speed-torque curves for the high-slip motor and a general-purpose squirrel cage motor

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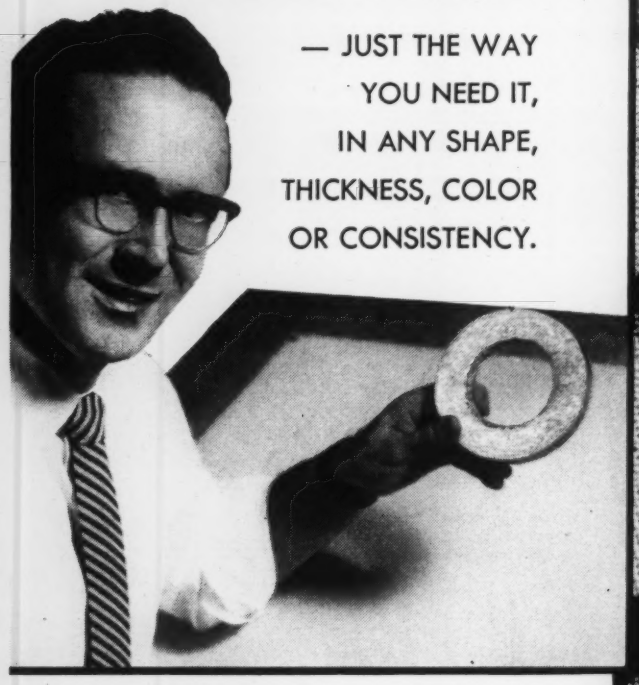

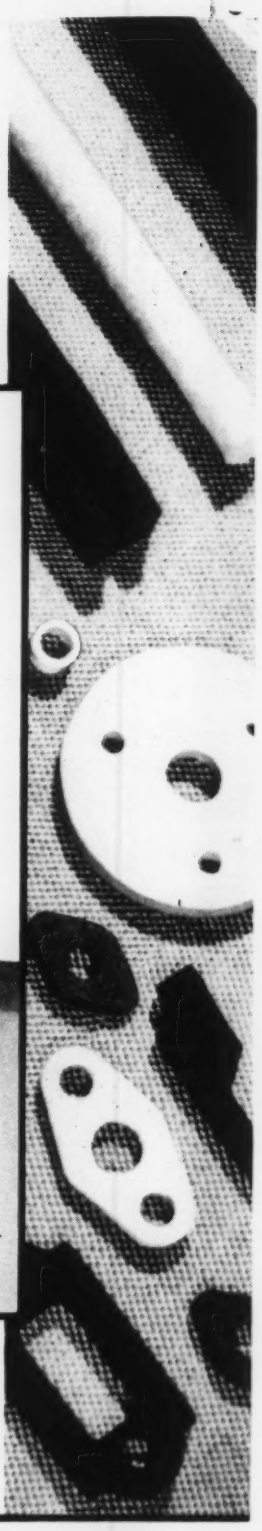

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hp) is usually designed for a starting torque of 110 to 150 per cent of full-load torque, depending on the speed, and a breakdown torque of 200 per cent. The slip speed is made as low as possible for maximum efficiency, generally running from one to two per cent.

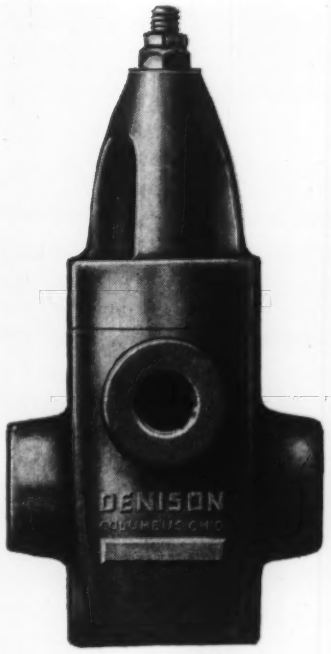
In the auto industry, where many large punch presses are used, TEFC high-slip motors are standard. Enclosed rather than open motors are used since the atmosphere frequently contains considerable dirt and metal dust that increases maintenance and shortens the life of an open motor.

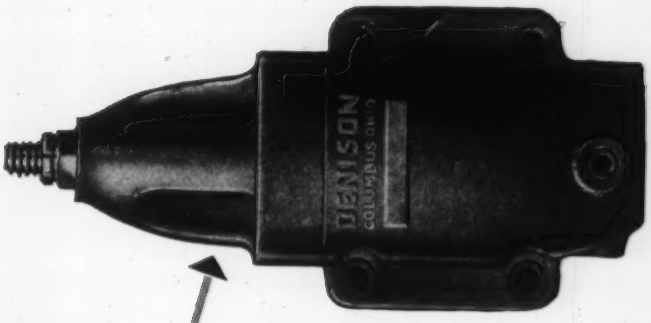
Slip Increases Losses

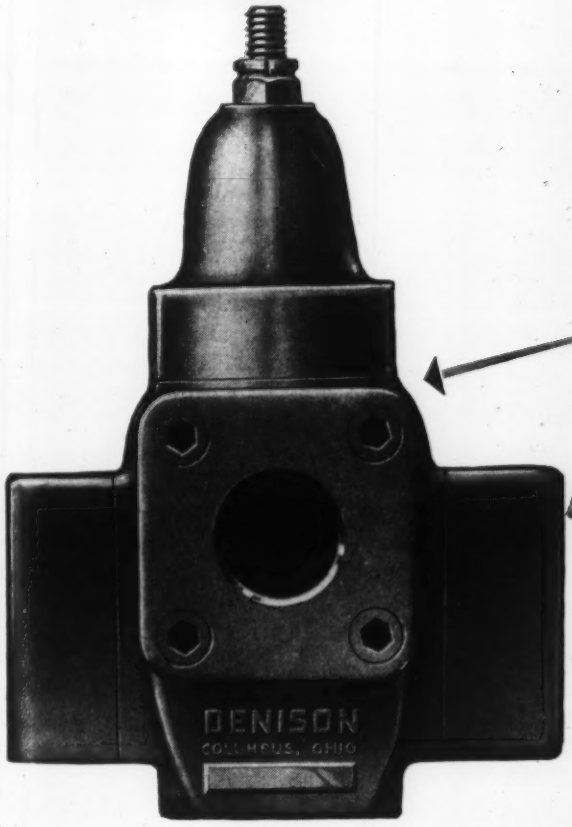
The rotor resistance of a general-purpose motor is quite low, and therefore the heat generated in the rotor is correspondingly low. Not so with the high-slip motor. To get the high starting-torque and high-slip characteristics required of the latter, it is necessary to increase the rotor resistance. Since slip speed is proportional to power losses in the rotor, heat losses are inherently greater. In fact, they are several times larger than losses in a low-slip motor of the same horsepower rating when running at rated load. The stator loss is also somewhat higher for the high-slip motor because its reduced efficiency and power factor increase the stator current for the same motor output.

Thus, heating considerations penalize the allowable horsepower rating of a high-slip motor in two ways. First, it's a lower-efficiency motor and additional heat is produced; second, the bulk of this additional heat is generated in the rotor, where heat transfer to the motor casing is comparatively poor. Therefore, if a conventional design is used, size and weight are greatly increased over a general-purpose motor of the same horsepower rating, because of the higher rotor losses.

The rotor construction used in the high-slip motor is adapted from a special open type motor in use for some time. There the problem was one of accelerating high-inertia loads where the heating was







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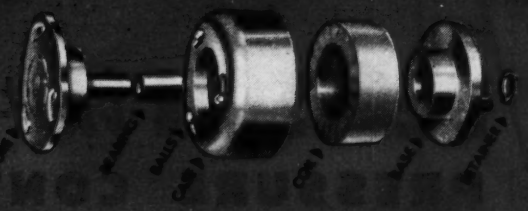

As can be seen from the exploded view, Ledex Rotary Solenoids are simply constructed with few moving parts. All parts are manufactured to exacting tolerances and are carefully inspected and assembled.

The copper wire coil, the heart of the Solenoid, was developed especially for this product. It is wound by a precision winding process that puts a maximum amount of magnet wire into available space . . . giving tremendous power to compact Ledex Rotary Solenoids.

six basic LEDEX ROTARY SOLENOIDS to choose from!

Model Number	2	3	5	6	7	8
Diameter	1⅛"	1¾"	1⅞"	2¼"	2¼"	3¼"
Torque lb.-in.*	½	1	5	10	25	50
Weight lbs.	⅛	¼	½	1	2¼	4½

*45° stroke intermittent duty.

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Design Abstracts

severe. Mechanically simpler, the new design is less costly to build. Heat-storage capacity is comparable to the conventional bar-rotor and adequate for most applications. Reduction of weight is about 40 per cent, and the space required for mounting is about 30 per cent less than the conventional construction. Smaller, lighter, and less expensive supporting structures or foundations are required.

Motors of the new construction are inherently better able to handle severe accelerating duty. Increased horsepower per unit of rotor weight (because of a smaller iron core) makes it possible to perform repeated accelerations — accelerations at a rate that would have been prohibitive before because of high rotor inertia when the motor was made large enough to dissipate the heat.

Rotor Runs Cooler

Improved power factor and efficiency result from maintaining the air gap at normal values. With the old conventional construction, the rotor was considerably hotter than the stator. To prevent mechanical interference when the rotor expanded, the air gap was made abnormally large. The electrical design of such motors was severely handicapped, but in the new design most of the rotor heat is generated outside the motor enclosure and the rotor body remains comparatively cool.

A decided increase in efficiency of around five per cent is realized with the new motor. This results from less windage loss, normal air gap, and reduced iron and copper losses that normally result from the smaller-size motor core.

Compared with the open forced-ventilated and filtered-air motor that is sometimes used to take the place of enclosed construction for punch-press drives, the extended-bar motor offers weight and space reduction of about 12 per cent.

Considerable field experience was gained with the extended-bar motor during the past two years. It's given excellent service in every instance. Besides applications utilizing the wide speed regulation of

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Design Abstracts

high-slip motors, such as for punch presses, they are also used on applications requiring repeated accelerations of high-inertia loads—hoists and centrifuges, for example. Here, their high starting torque and rotor heat-storage capacity are desired. They have also been applied to conveyors, and large presses.

From an article entitled "Slipping the Induction Motor" appearing in the September 1952 issue of the General Electric Review.

Oil Effects On Rubber Properties

By J. R. Beatty and A. E. Juve

Research Center
B. F. Goodrich Co.
Brecksville, O.

RUBBER and synthetic rubber-like materials, due to their elastic properties, are particularly suited for gaskets, seals, suspensions, and other uses where strain is essentially compressive. The stress resulting from this strain is widely utilized as a seal for fluids or gases. Many of these applications are subject to swelling agents, such as oil, from their surroundings either through design or accident. Swell phenomena have been investigated with rubber compounds in the presence of swelling agents, but in these tests no strain was imposed on the rubber and the effect of strain, particularly compression, has been reported only to decrease the rate of imbibition of oil.

To investigate the effect of mineral oil swelling agents on rubber compounds, four stocks were tested:

1. Natural rubber stock cured with tetramethyl thiuram disulfide.
2. GR-S stock.
3. Neoprene GN stock.
4. Hycar OR-15 stock cured with tetramethyl thiuram disulfide.

All were 60 ±5 Shore "A" hardness and were loaded with semi-reinforcing furnace black. The continuous stress relaxation of the samples was followed as a function of time, in the presence of three different mineral oils.

Test Results: In many applica-

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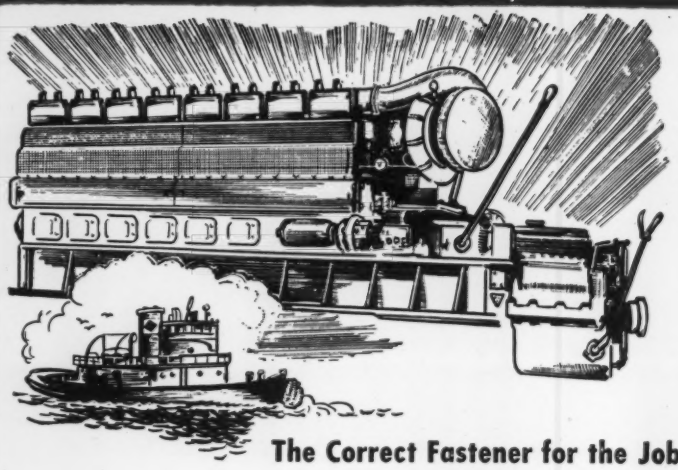

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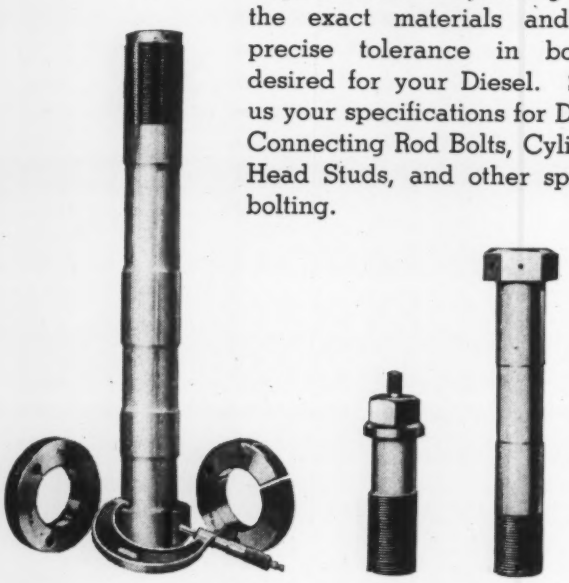

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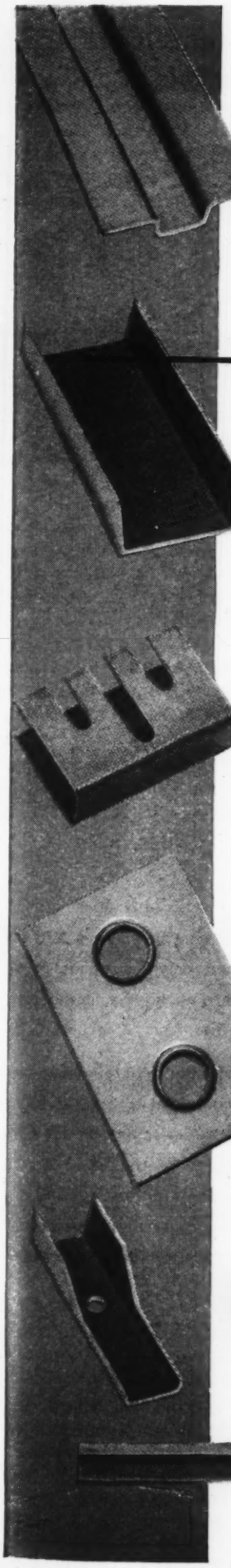
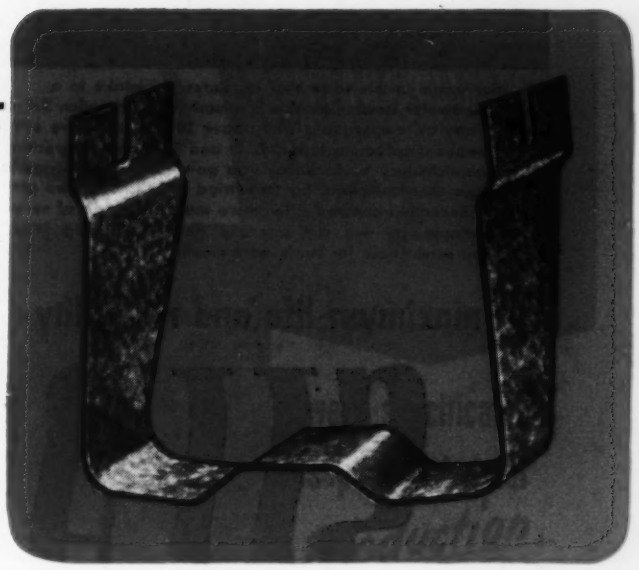
tions, the deterioration of physical properties of rubber brought about by contact with oil severely limits its application and/or service life since swollen rubber is usually weak in tensile strength and low in modulus. The process by which this deterioration occurs is probably twofold. The solvent action weakens molecular attraction forces in the rubber while the double bonds are stretched, which may lead to accelerated oxygen attack.

In intermittent stress relaxation tests in which the sample is allowed to swell unconfined between measurements of stress at constant deformation, the stress relaxation is accelerated by the presence of oil. However, continuous stress relaxation tests show a different behavior. In some cases, measurements of stress have shown that after 5000 hours test time the values exceeded the initial stress, and were always equal to or greater than the comparable measurements in air. In these tests, the data are practically identical for an induction period which varies with the temperature and polymer, regardless of whether oil or air is in contact with the samples. After this induction period the action of the oil becomes apparent as an increase in stress above the values obtained in the presence of air. This increased stress was observed for times up to 10,000 hours.

Effect of Oil: The three oils used in this investigation cover the range of swelling normally encountered in usual petroleum-base oils—low, medium and high. Data for continuous stress relaxation with natural rubber and GR-S samples immersed in the various oils at 24 and 70 C show that both increase considerably in all three oils. In every case ASTM No. 1 oil (low swell) caused the smallest stress increase, ASTM No. 2 (medium swell) was intermediate, and ASTM No. 3 (high swell) produced the greatest stress increase. The oil-resistant type rubbers, neoprene and Hycar OR-15 were practically unaffected by ASTM No. 1 oil with respect to stress relaxation properties while ASTM No. 2 and 3 caused an appreciable increase in

For Formed Shapes...





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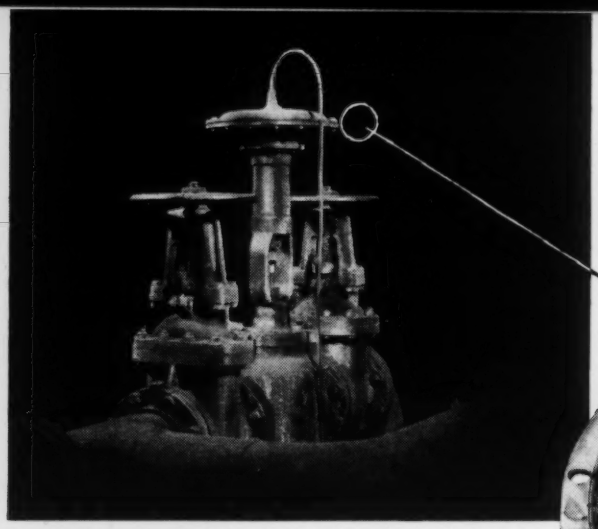

The diaphragm in this valve that regulates the intake to a boiler feedwater storage tank, is in almost constant motion 24 hours a day at temperatures well above 100°F. Successive synthetic rubber diaphragms lasted 7, 11 and 13 months respectively. That's unsatisfactory performance in a power house supplying energy to a large chemical plant. So they tried a Silastic coated glass diaphragm. Recently inspected after more than 78 months of service, the Silastic diaphragm was still soft and flexible; showed little wear; appeared serviceable for many more months.

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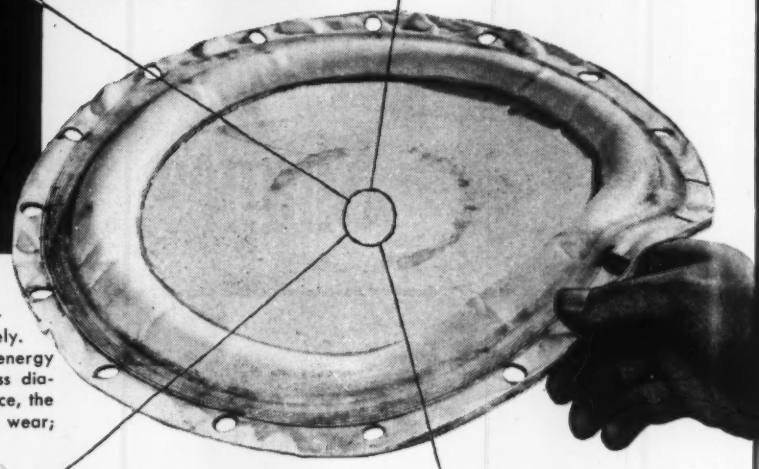

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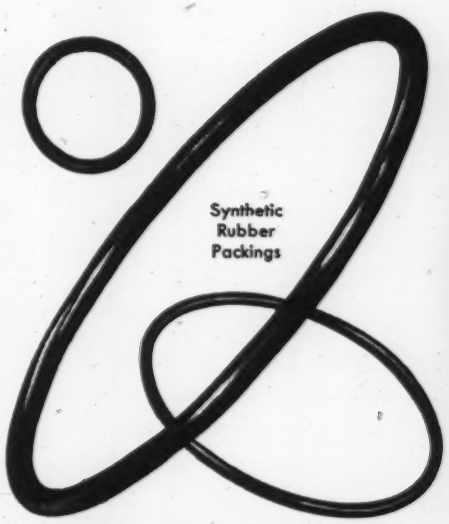
stress after considerable time. The relatively long time for the onset of stress increase is in agreement with other investigators who found that mechanical stress, applied so as to resist the expansion of the rubber, reduces the amount of oil absorbed and thus the swell.

Effect of Polymer: Polymers are affected by oil depending on their molecular constitution. Polar groups or halogen groups contribute to the oil resistance in proportion to the amount present. Natural rubber and butadiene-styrene copolymers, such as GR-S, are not noted for their resistance to oils; they are easily swelled in poor swelling agents. From comparative data for compounds of natural rubber, GR-S 10, neoprene GN, and Hycar OR-15 for ASTM No. 3 oil at 70 C, the rubbers were rated in the following order: Hycar OR-15 showed the least change, neoprene considerably more, and GR-S and natural rubber the most.

Effect of Temperature: Increasing the temperature decreases the induction period and increases the rate and magnitude of stress increase. In effect, oil reactivity is increased with respect to the rubber and the oil-resistant rubbers are affected at the higher temperatures. This is due to increased solubility and decreased molecular attraction between molecules of the rubber.

Test Significance: The practical implications of this study are that rubber compounds which swell in the presence of oil have a property which may be utilized in some applications for a useful purpose. Examples are O-ring seals, and other types of gaskets where the rubber is used in compression. In these cases, the stress decays more slowly with time and in some cases the force would increase and the tendency to leakage would be minimized. For these experiments the sample was relatively unconfined except for the direction of loading with only low frictional forces which tended to prevent increase in volume. It was noted that with natural rubber and GR-S the stress



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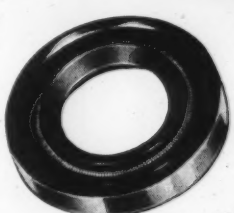

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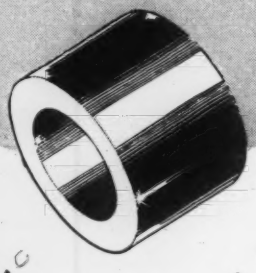

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Design Abstracts

dropped markedly at 10,000 hours which is a result of the sample reaching equilibrium with respect to swelling by the oil and the stress then decreases depending on the oxidative scission of bonds in the same manner as found for tests conducted in air. However, according to others, the attack of swelling agents accelerates oxidation so it is possible that this oxidative scission might be in addition to that normally measured in air.

From a paper entitled "Stress Relaxation in Compression of Rubber and Synthetic Rubber Vulcanizates Immersed in Oil" presented at the ASME Fall Meeting in Chicago, Ill., September 1952.

Radioactive Isotopes For Industry

By Paul C. Aebersold

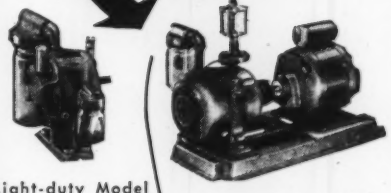
Director
Isotopes Division
United States Atomic Energy Commission
Oak Ridge, Tennessee

RADIOACTIVE isotopes may be used either as radiation sources or as tracer atoms. In the first instance, they are used in much the same way as radium and X-ray machines have been used for a number of years. The principal advantages of reactor-produced isotopes over older sources of radiation lie in their greater availability and greatly reduced costs and in a much wider choice of type and energy of radiation.

The more unique application of radioisotopes is their use as tracer atoms. Since the radioactive atoms of an element behave chemically like the ordinary stable atoms of the same element, they go along with them in all kinds of processes. But because of the radiations given off by the radioactive atoms, they can always be distinguished. By use of the proper instruments, these radiations can be made to produce signals which may be seen or heard or mechanically counted. As tracer atoms, radioisotopes serve as the basis for a powerful new analytical technique—the tracer technique.

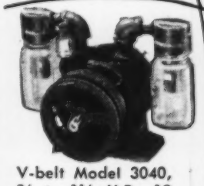
The tracer technique gets its power from a combination of ex-

Specify these GAST rotary-vane VACUUM PUMPS to solve your original equipment problem—

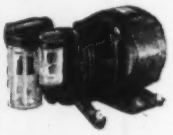


Light-duty Model 0440, 1/3 H.P., 3.8 C.F.M., 15" to 26" vac. Direct or V-belt drive.

Heavy-duty Model 1065, 1/4 to 1 1/2 H.P., 3.8 to 21 C.F.M., 26"-28" vac. Direct or V-belt.



V-belt Model 3040, 3/4 to 1 1/4 H.P., 19 to 24 C.F.M., moderate vac., V-belt drive only.



Integral Motor-Pump Model 0210, 1/4 H.P., 1.3 C.F.M., to 27" vac.

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Gain lower maintenance and higher performance for your own products. Select the pump that fits your application from any of these types — in numerous sizes and combinations. Choose integral-motor, V-belt or direct drives, with or without bases or accessories, such as lubricators, mufflers, fans, filters.

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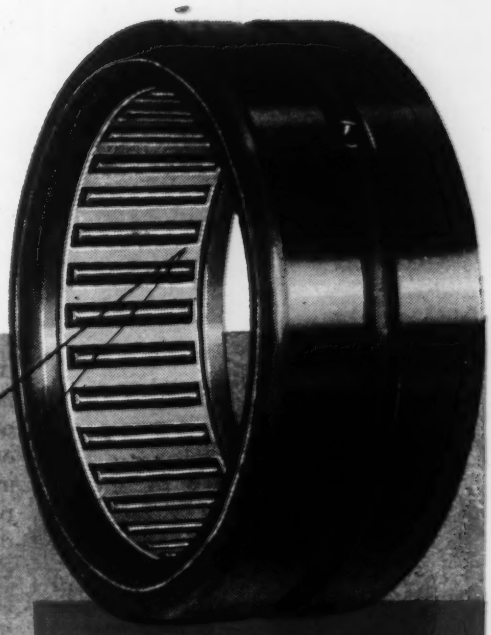
AIR MOTORS - COMPRESSORS - VACUUM PUMPS
(TO THREE H.P.) (TO 30 LBS.) (TO 28 INCHES)
GAST MANUFACTURING CORP., 109 Hinkley St., Benton Harbor, Mich.

This ORANGE *Cage Design*

assures permanent alignment of rollers

--prevents roller skewing!



TRUE RUNNING IN ANY POSITION

on

--conventional applications
--vertical installations
--overhung mountings
--relatively high speed applications
--and are less affected by misaligned mountings and uneven loading.

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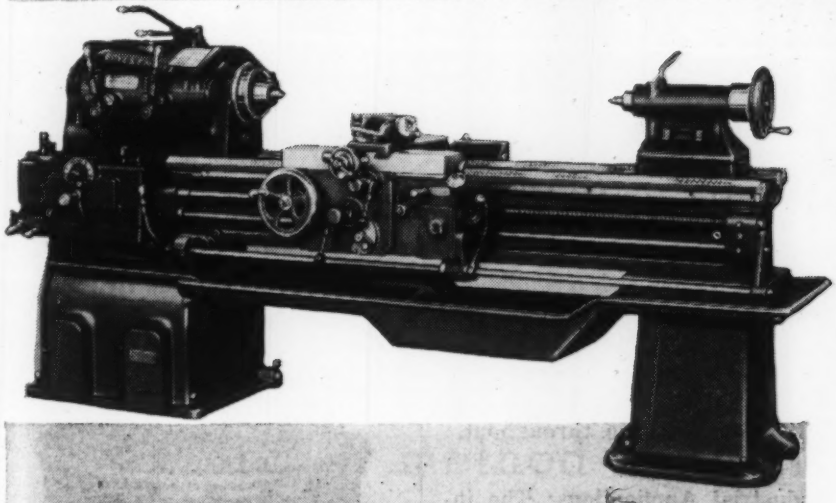
NEEDLE BEARINGS



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Orange Cage Type Needle Bearings are used as follows: One on the gear box center shaft—three in train gears from spindle to gear box—one in the apron. Boye & Emmes engineers selected these bearings "because of their high radial capacity, small outside diameter and comparatively large inside diameter." They report trouble-free performance from all machines in the field.

Orange Cage Type Needle Bearings provide the big advantage of high load capacity in small space—plus the additional feature of permanent roller alignment. This permits you to design needle bearings into many applications heretofore unsuited to other needle bearings.

In the Orange cage design, square end rollers are retained in pockets of a free-floating, land-riding cage of anti-friction, non-ferrous metal. The cage merely guides—does not wear on rollers. All rollers and races are "Pentrate" finished to reduce corrosion and friction.

This combination of operating characteristics in Orange Cage Type Needle Bearings provides every installation with quiet, precision running and long, trouble-free service.

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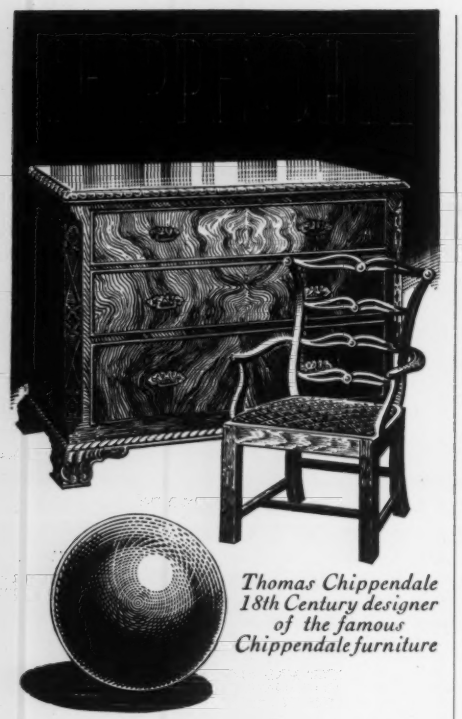

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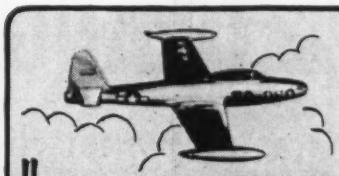
Design Abstracts

treme sensitivity and unique specificity. So sensitive is the method of measuring the radiations from radioisotopes that it is possible to detect the presence of atoms with millions to billions of times the sensitivity possible with any other physical and chemical means now known. Indeed, it is not difficult to detect radioisotopes that have been diluted as much as a billion or ten billion times while dilutions of more than a trillion are attainable. This means that it would be possible to detect one ounce of radioactive material mixed uniformly in 100 million tons of nonradioactive material. Or to put it into more concrete terms, one could detect as little as one ounce of radioactive sugar uniformly mixed in two billion 100 lb sacks of ordinary sugar.

The unique specificity of the tracer technique means simply that radioisotopes provide the ability to follow a specific batch of atoms through a complicated system irrespective of all the other atoms present and of all the chemical processes that may be going on. For example, in a biological experiment it would be possible to trace an isotope in a soil nutrient through a plant grown on the soil, through a cow fed on the plant, and finally through a rabbit fed on milk obtained from the cow. Even though the isotope would pass through a number of complex processes, its tell-tale radiation would permit its positive identification throughout.

Industrial Applications: The industrial applications of radioisotopes, like applications in other fields, depend on using the radiomaterial both as a source of radiation and as tracer atoms. Industry has used radiation sources quite extensively in its quality control and plant-scale operations. Its use of tracer atoms, however, has been largely restricted to research activities.

The simplest type of application depends merely on measuring the change in intensity of radiation from a radioactive source when something is placed between it and the detecting instrument. The use of radioisotopes in radiographic



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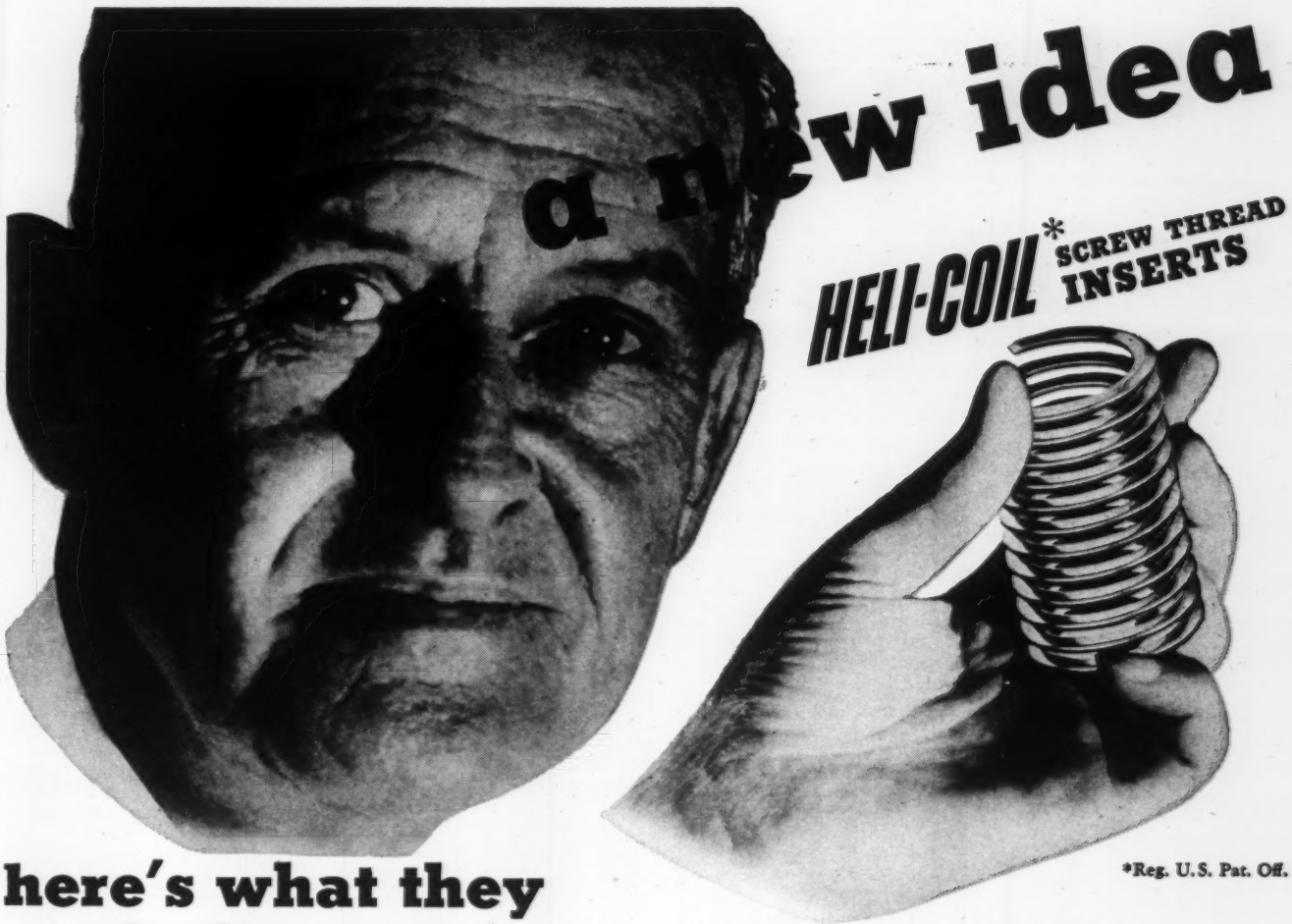
REGARDLESS OF THE SIZE AND TYPE OF YOUR MACHINERY, LUBRIPLATE LUBRICANTS WILL IMPROVE ITS OPERATION AND REDUCE MAINTENANCE COSTS.



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they save money because they strengthen threads and make *fewer* fastenings do the same holding job... they make *lighter* bosses and flanges practical... and they *save* weight in *two* ways: (1) by permitting use of cap screws instead of bolts and nuts or studs and nuts; (2) by putting smaller, shorter, fewer cap screws to work than required for unprotected threads.

they protect your product from thread wear and stripping for life in every kind of metal, in plastics or wood. They preserve your customer good-will by preventing complaints about thread failure.

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So easy to use! Average time to install 3 seconds!

Drill... Hole is drilled in conventional way—right on production line. **Tap** ... Hole is tapped with ***Heli-Coil*** tap to receive insert—right on production line. **Install**... Insert is installed in tapped hole with hand or machine inserting tool —right on production line.

What *Heli-Coil* Inserts Are

Heli-Coil Inserts are precision formed thread liners of stainless steel or phosphor bronze wire, diamond-shaped in cross-section. They are available for National Coarse, National Fine and Unified threads, pipe threads and aviation and automotive spark plug threads. They are made in all standard sizes and lengths for assemblies requiring Class 3, 3B, 2 or 2B fits.

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☐ Attached is drawing of our product. Where do you recommend using *Heli-Coil* Inserts?

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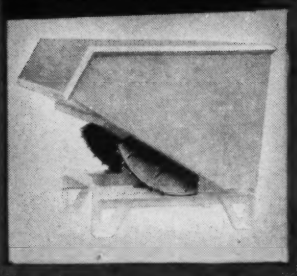
Case History M-117

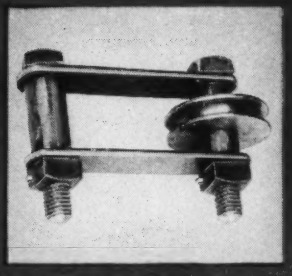
You can benefit through SUPERIOR'S PRODUCT DEVELOPMENT SECTION . . .

. . . when you're up against problems like these:

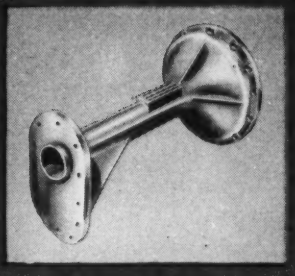
PROBLEMS:



HIGH ASSEMBLY COSTS... due to weldments made up of many pieces, as in these rocker arms.

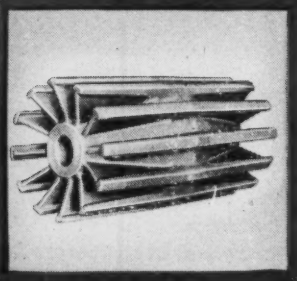


HIGH FABRICATION COSTS ... for example, this clevis assembly made from twelve separate pieces.

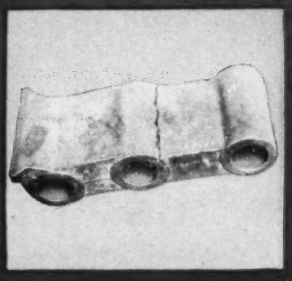


EXCESSIVE CASTING COSTS ... as in this one-piece cast steel tractor drive spacer, required in 5 different lengths.

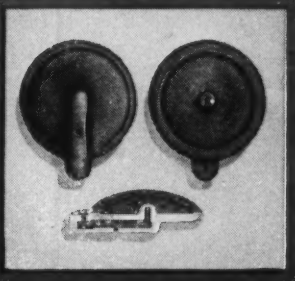
POOR APPEARANCE... resulting in sales resistance to end product, as in this wheel spindle.



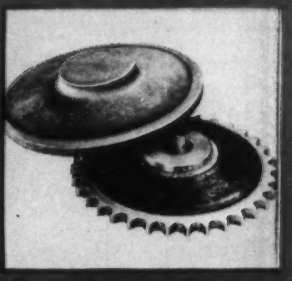
COMPLICATED STRUCTURES ... like this 380-pound one-piece steel casting where center core was difficult to anchor.



BREAKAGE . . . due to improper distribution of the metal, such as in this cast steel knuckle arm.



LEAKERS... result of uneven metal sections, as in this cast steel hydraulic cylinder head.



MACHINING LOSSES... result of uncontrolled shrinkage as in this cast steel sprocket blank.

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Since 1916

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testing, in thickness gages, in liquid level gages and in density meters all depend on this one simple principle.

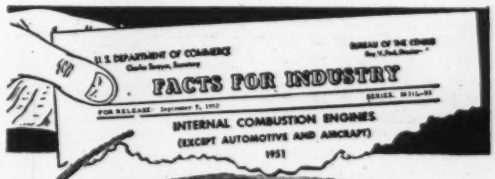
Radiation Applications: Radiographic testing, a comparatively old application of radioactivity, consists of placing a radioactive source on one side of the weld or casting to be tested and a photographic film on the other side. A darkening of the developed film indicates the location of any flaws or cracks since more radiation will penetrate through these places and hence cause greater exposure to the film.

Until quite recently, naturally occurring radium and radon were the only radioisotopes available for this purpose. Today, however, an increasing number of industries are using radioactive cobalt instead. Besides being more readily available and easier to handle than radium, radiocobalt can be obtained in units of greater radiation strength as well as in any desired shape and size. Radiocobalt is also 5 to 40 times cheaper than radium depending on whether the radium is purchased or rented.

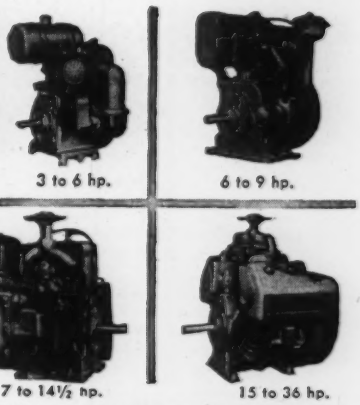
The radioactive thickness gage makes use of the same simple principle of measuring the change in intensity of a beam of radiation from a fixed source. The radioactive source is placed on one side of the sheet material whose thickness is to be measured and a radiation detection device such as a geiger counter or ionization chamber on the other side. Amount of radiation transmitted through the material is inversely proportional to its thickness.

The advantage of radioactive thickness gages over other devices designed for the same purpose is that no mechanical contact is necessary and hence they can be used without stopping or cutting the rolling sheet. Radioactive thickness gages also guarantee measurements of greater sensitivity and higher precision. Further, they are adaptable to automatic control of the roller settings.

The radioactive liquid level gage is similarly based on measuring the change in intensity of a beam of



Proof of Top Preference for



WISCONSIN HEAVY-DUTY Air-Cooled ENGINES

Based on data contained in a "Facts for Industry" report released on Sept. 5, 1952 by the U. S. Bureau of the Census, an aggregate average of 50.61% of all carburetor type internal combustion engines produced during 1950-'51 within an 11 to 175 cu. in. displ. range (approx. 3 to 40 hp.) were WISCONSIN HEAVY-DUTY AIR-COOLED ENGINES (exclusive of aircraft, automotive, outboard marine and "captive" engines built by various manufacturers for use on their own equipment).

Here is positive proof of top preference for Wisconsin Engines both by original equipment manufacturers and users of power-operated equipment. Proof of constantly growing recognition of the special adaptability of these fine engines to fit both the machine and the job. Proof of heavy-duty dependability and trouble-free air-cooling under weather and climatic extremes.

Wisconsin general-purpose Air-Cooled Engines have been *pre-judged* and *pre-selected* by more power-wise purchasers than ALL other makes of engines combined, within a 3 to 40 hp. power range. Perhaps it's your turn to specify "Wisconsin". Descriptive literature and engineering data on request.

WISCONSIN MOTOR CORPORATION
World's Largest Builders of Heavy-Duty Air-Cooled Engines
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Design Abstracts

radiation from a fixed source. The source is sometimes mounted on one side of the tank or vessel containing the liquid and the radiation detector on the other side. This particular adaptation has, for example, been found advantageous in measuring the height of molten metal in a cupola since problems of corrosion and high temperatures can be eliminated. For other applications it may be found better to place the radiation source in a float on the surface of the liquid and the radiation detector at the top of the tank.

Tracer Applications: Radioisotopes can also be used as movable sources of radiation to follow an object or the movement of a bulk mass of material. Here the radioactivity is used as a marker which can be easily identified even though it is not visible.

Perhaps the best known and most widely used movable source type application is following the flow of oils through pipe lines. It is common practice to use the same pipe line to transport a wide variety of crude or refined oils. The location of the interface or boundary between the two oils must be known in order to route different oils to different take-off points and terminals along the line. The radioisotope method is based on injecting into the line a small amount of radioactive material just at the interface as a product is changed. Geiger counters detect and record the passage of radioactivity in the interfaces at various points along the line. Clean separation of the different oils at the receiving end means a large saving in oil and money.

General Considerations: All of the applications described thus far lend themselves to routine use in production or quality control operations. With the exception of leak detection, oil well acidizing and pipeline flow applications, the radioisotope is used as a sealed source, that is, it is encapsulated in a leaktight container from which it cannot escape and become a possible source of contamination. In each instance the usefulness of the

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- Norgren 1-stage Cylinder Gas Regulators are specially built to regulate the pressure of cylinder gases, from tank supply to point of use, as accurately as most 2-stage types. Outstanding features include close control of delivery pressure, positive delivery without "creep," and exclusive ball-pivoting lower spring rest which assures permanently friction-free operation.

- Maximum primary pressure of 3000 psi. Maximum working pressures of 100 psi., 175 psi., and 450 psi.

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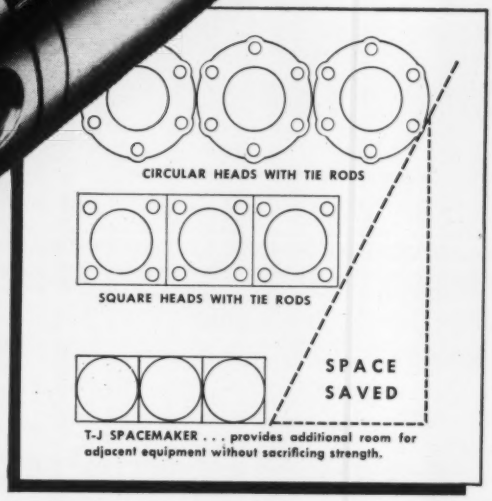

T-J SPACEMAKER . . . provides additional room for adjacent equipment without sacrificing strength.

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- SOLID STEEL HEADS.
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- LEAKPROOF CYLINDER HEAD TO BODY CONSTRUCTION.
- RELATIVE PORT POSITIONS MAY BE ROTATED WITHOUT DISASSEMBLY OF CYLINDER AND LOCKED IN DESIRED POSITION.
- HEAVY DUTY, HI- TENSILE, HARD CHROME PLATED PISTON ROD.

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RIVITORS . . AIR AND HYDRAULIC CYLINDERS . . CUTTERS . . CLINCHORS

Design Abstracts

radioisotope is based simply on the radiation which it emits. Notwithstanding the fears of some, the radiation from a source of this type or from any other radioisotope cannot induce radioactivity into materials, that is, make them radioactive. And in those instances where the radioactive material is introduced directly into the system being studied, as for example into the oil in the pipeline flow determination, the quantity required is so small as to create no public health hazard. In the pipeline flow application the amount of radiomaterial used is so small that the radiation which it emits is less than that of an ordinary luminous dial watch.

As tracer atoms, radioisotopes may be used to study the transfer of material by physical and physical-chemical means as well as the mechanism of chemical reactions. Perhaps the simplest example of this type of application is the use of tracers in measuring the vapor pressure of metals. Although this measurement can be made in other ways, the use of radioisotopes permits a more accurate measurement in a shorter period of time. Other examples of similar physical transfer measurements include diffusion measurements, particularly those of self-diffusion, and wear determinations. A number of companies are using radioisotopes to study the wear of piston rings and other machine parts during operation. Tests of this type using radioisotopes have been found to yield as much information in a few hours as could be obtained by other methods in days and weeks. Further, the radioisotope test gives much more reliable comparison data than can be otherwise obtained.

These are but a few of the ways in which industry has already applied the radioisotope to research and development activities as well as to plant production problems. Most of the other applications not described here are, however, based on the same principles.

Application Factors: Unfortunately, there is no clear cut and easy way of determining whether radioisotopes may be used to advantage

CONTINENTAL AIR FILTERS, Inc. STANDARDIZES WITH OHIO STOCK GEARS AND REDUCERS

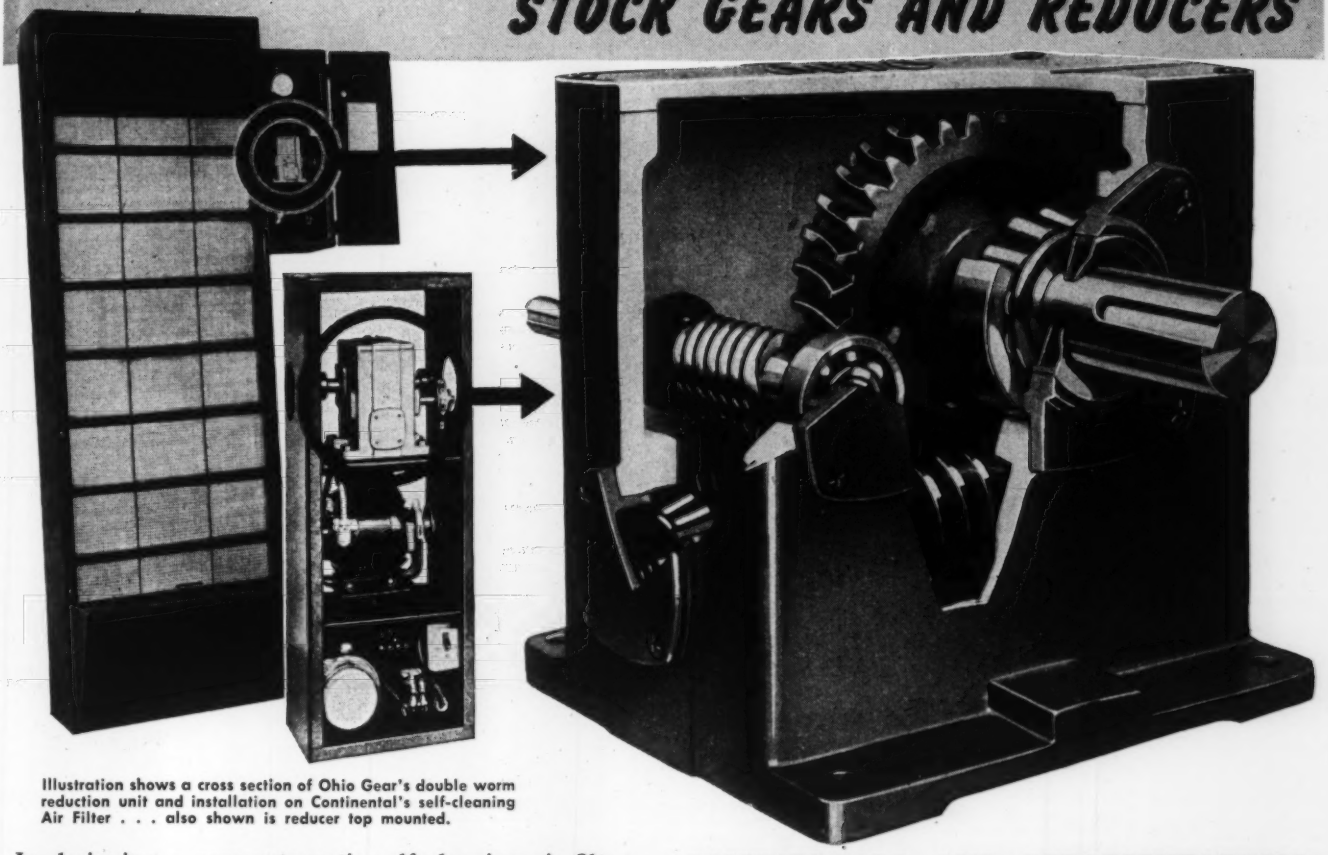

Illustration shows a cross section of Ohio Gear's double worm reduction unit and installation on Continental's self-cleaning Air Filter . . . also shown is reducer top mounted.

In designing a new automatic self-cleaning air filter, Continental Air Filters, Inc. of Louisville, Ky., gave careful consideration to the known short-comings of existing automatic filters. Continental made exhaustive studies of all accessories to the filter, and for reasons of sound engineering design, dependable and accurate performance, reputation and physical impactness, an Ohio Gear reducer was chosen. Just as industry depends on Continental Air Filter for the important function of keeping the air clean, so does Continental depend on Ohio Gear for accurate and consistent performance of their unit. This was an important factor in the largest installation of automatic self-cleaning filters under roof, the Ford Motor Company's Foundry, at Cleveland, Ohio. Continental considers the dependable operation of Ohio Gear reducers partially responsible for its success. Perhaps Ohio Gear can serve you as well. Get in touch with their nearest distributor or write direct to THE OHIO GEAR COMPANY, 1338 East 179 Street, Cleveland 10, Ohio.

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If you want longer V-Belt wear and lower V-Belt costs just make this simple test. Bend any V-Belt that has *straight sides* and—as it bends—*feel* the sides bulge out! (See Fig. 1-A, below)

This out-bulge forces the belt to press unevenly against the V-pulley and of course wear on the belt is concentrated where it bulges most. Naturally this shortens the life of a *straight-sided* V-Belt.

Now, make this same test with the belt that is built with *concave sides*—the Gates Vulco Rope!

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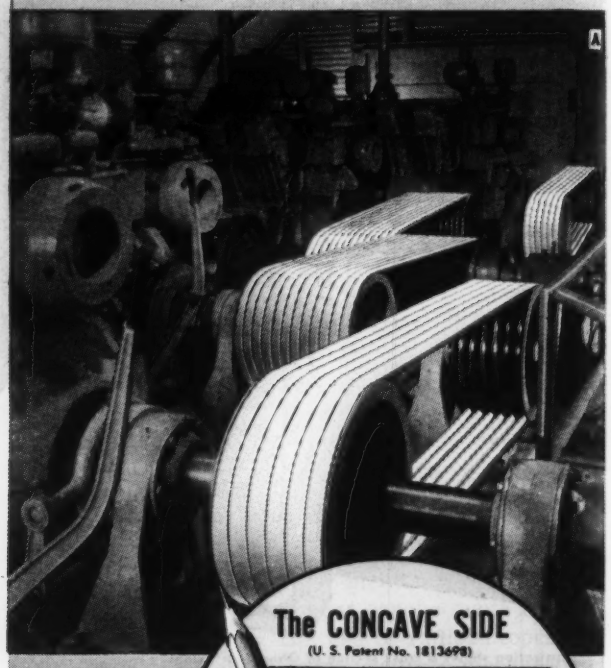
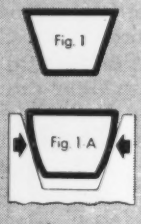


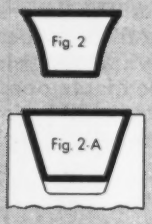
What Happens When a V-Belt Bends

Straight-Sided V-Belt



How a Straight-Sided V-Belt Bulges in the Sheave-Groove. Sides Press Unevenly Against the V-Pulley, Causing Extra Wear at Point Shown by the Arrows.

Gates Vulco Rope With Concave Sides



The Concave Sides Fill Out to Precise Fit in Sheave-Groove. No Side-bulge! Sides Press Evenly Against the V-Pulley —Uniform Wear and Longer Life!

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in a new research or production problem confronting a plant. Possibly some of the applications described here may indicate where radioisotopes might be applicable. Generally, they still remain primarily a laboratory rather than plant tool. However, an increasing number of routine applications are being found where health-safety limitations have been overcome, both from the standpoint of using the materials in the plant as well as from the standpoint of possibly leaving residual radioactivity in the market product.

It should be remembered that radioisotopes require special handling, special equipment and very precise techniques. Each proposed application should be weighed separately against other ways of doing the same job. In general, radioisotopes should only be used if there is no other way of solving the problem, or if they appreciably simplify the job or guarantee better precision or sensitivity of measurement.

From a paper entitled "Current Uses of Radioactive Isotopes in Industry" presented at the AMA Manufacturing Conference in Cleveland, December 1952.

Designing the 50,000 Ton Forging Press

By Fred T. Morrison and R. G. Sturm*

PRODUCTION of large forgings and extruded shapes has become a primary goal of the Air Force industrial mobilization program. First step in the program has been the design and construction of forging and extrusion presses to meet these needs. Included are several closed-die forging presses ranging in capacity up to 50,000 tons.

In the design of forging presses larger than ever have been built, it was necessary to (1) insure that the presses can be made with existing manufacturing facilities, (2) make the equipment safe in its operation, and (3) consider the trans-

* F. T. Morrison is Chief Stress Analyst, Loewy Construction Co., New York, N. Y., and R. G. Sturm is Director of the Auburn Research Foundation, Auburn, Ala.

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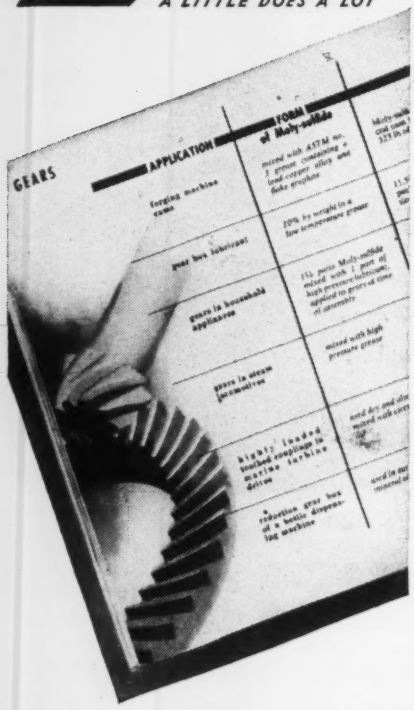

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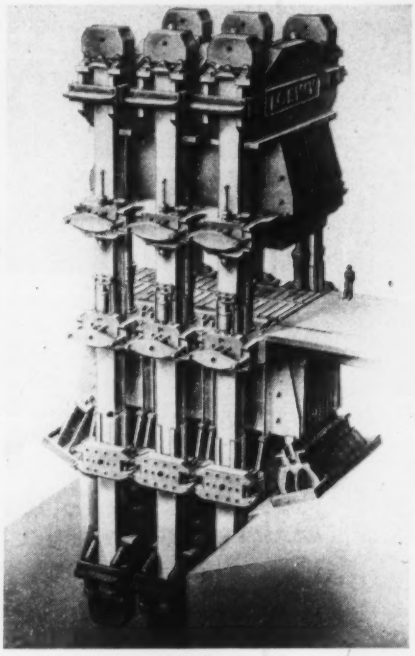
Design Abstracts

portation facilities available for delivering the press components from the shop to the erection site. From a review of these criteria a new concept of press design was evolved.

This new design by the Loewy Construction Co., shown in the accompanying illustration, is a 50,000 ton capacity pull-down press with nine hydraulic cylinders and six tierods or columns. Overall height of the press is approximately 110 feet. All of the structure below



Artist's conception of the 50,000 ton capacity closed-die forging press designed by Loewy Construction Co.

the lower platen is submerged below the floor or working level making the super-structure at its highest point approximately 60 feet above floor level. Total weight of the press is approximately 10,000 tons; the moving parts weigh 6000 tons.

Design Features: Main structural members of the press are composed of composite and transverse forged steel slabs which, when assembled and restrained by shrunk tierods, provide for rigid upper and lower platens thus minimizing press platen deflections. Main tierods or columns are not of the conventional cylindrical type but are rectangular in cross-section and made up in three laminations approximately

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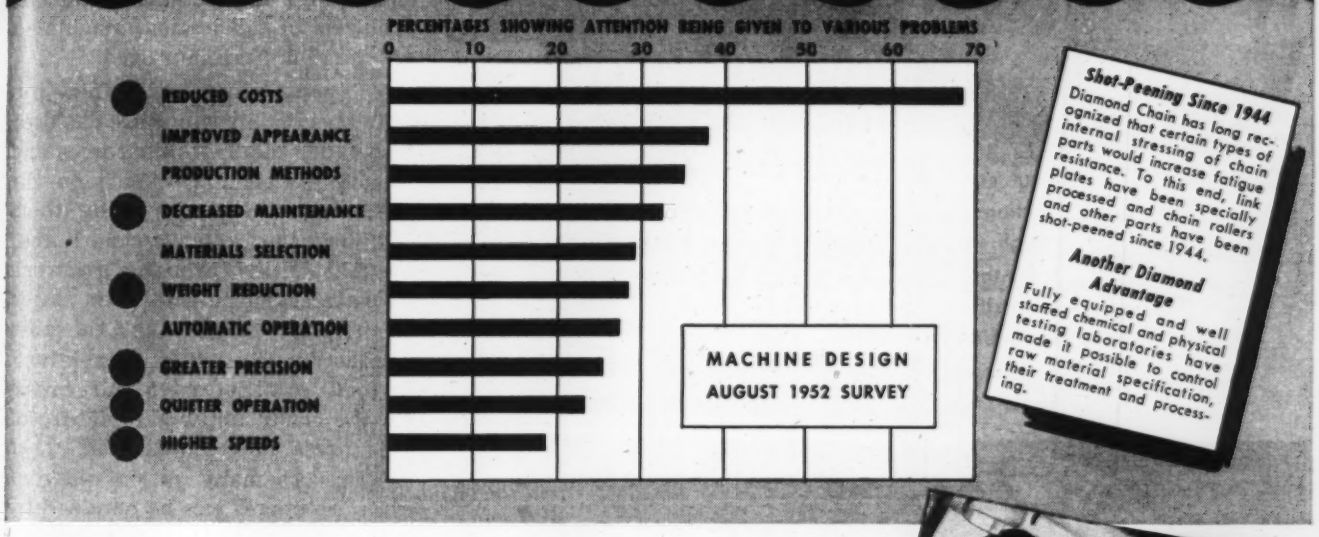

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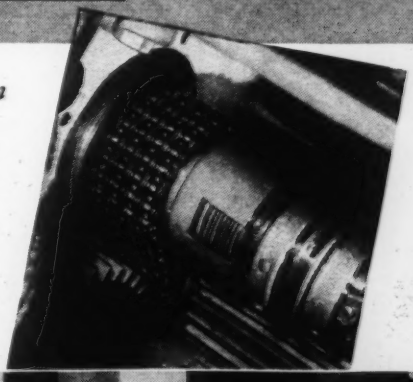
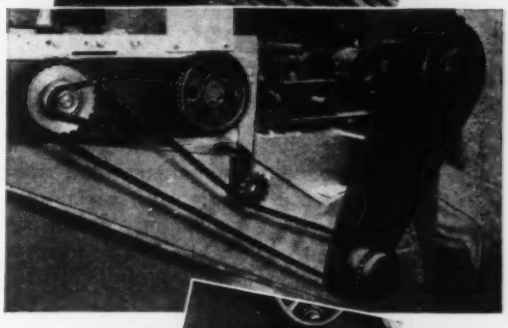
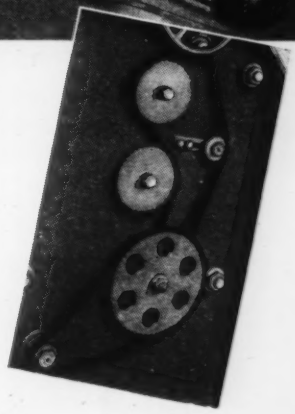
- **QUIETER OPERATION**—The precision manufacture of all parts, the free roll of bushings and rollers result in smooth, quiet operation at all speeds.
- **HIGHER SPEEDS**—Diamond Roller Chains are so light in relation to power transmission capacities and tensile strengths that stresses due to centrifugal force are negligible until linear speeds approach 30,000 f.p.m.







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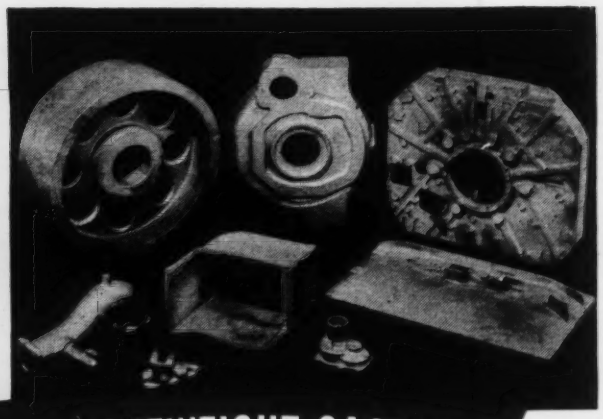

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110 feet long. Since each of the six main tierods weighs in the neighborhood of 600,000 pounds it is impossible to obtain them in a single steel forging which would require ingots of steel far heavier than the largest which can be made with present know-how. By making each main tie-rod in three individual rectangular sections, sounder forgings are obtained, and the problems of fabrication, machining and handling are improved.

The press is powered by nine hydraulic cylinders which are disposed to balance the hydraulic forces and reduce the bending effects on the structural members, putting them in almost pure compression. Forces are transmitted through a gridwork of plate beams to the lower platen of the press, and through the main tierods to the upper entablature. In contrast with conventional presses, the entire upper entablature of this press moves with the upper platen. As many as six different pressure stages can be obtained by using various combinations of the nine hydraulic cylinders and by selecting either rated hydraulic pressure of the accumulator system or by using an intensifier arrangement.

Automatic Compensation

To protect the press against excessive eccentric loads which would cause damage to either the main tierods or to the press structure itself, a unique type of hydraulic force compensating system has been devised. Its action is entirely automatic and the degree of load compensation is a function of the rotational deflection of the upper entablature of the press when subjected to an eccentric loading. In addition to the compensating system, an automatic strain gage protective system has been incorporated into the press. When preselected values of strain in the tierods are exceeded, the hydraulic system is automatically unloaded thus preventing damage to the press.

In designing a machine whose components are as enormous and massive as those required for a 50,000 ton capacity die forging press, not all design problems are

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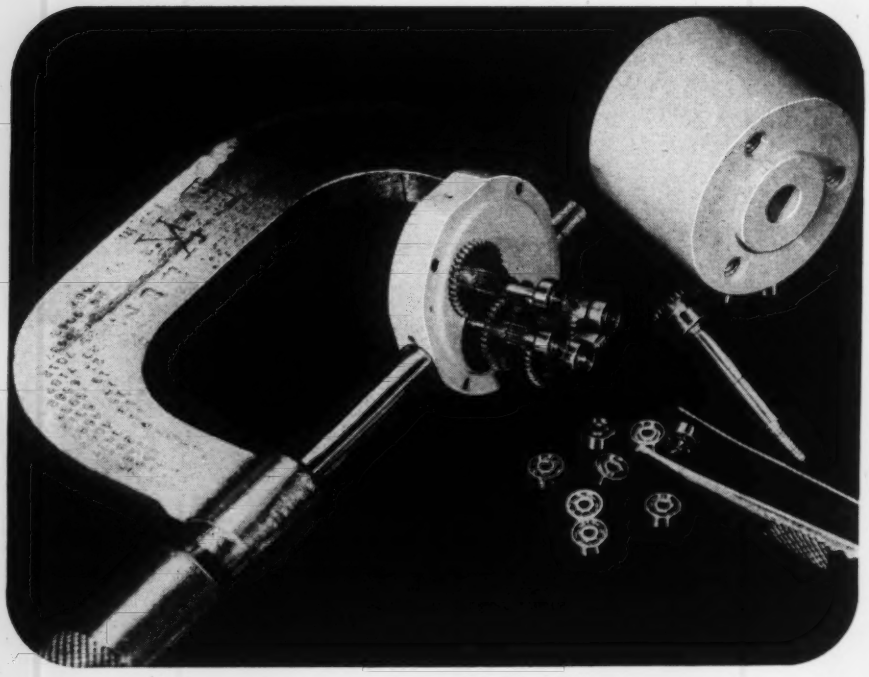

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capable of solution on the drafting board. And if they were, a confirmation of such results would be desired in order to avoid costly repair of parts and replacements once the machine is put into operation. Determination of the best shape for load transmitting members to keep to a minimum the effects of stress concentration cannot readily be calculated. Furthermore, the analysis of very complex shapes cannot be approached in a straightforward manner by pure analytic computation. Hence, resort has been made to experimental methods which include two and three-dimensional photoelastic studies as well as the testing of scale models.

Components of the 50,000 ton press investigated by experimental methods were the main tierods, hydraulic cylinders and cylinder holding ring.

Main Tierods: Failure in round press columns with threaded anchor nuts are not infrequent and invariably occur at the root of the first thread immediately adjacent the nut bearing surface which is subject to large stress concentrations. In addition, a nonuniform loading exists around the shoulder of the nut as a result of bending and shear deflections of the crossheads, giving rise to higher than average stresses at the root of the thread.

Anchors of the rectangular columns used in the new press do not utilize threaded connections. Anchoring is achieved by means of enlarged sections integrally forged with the main column or tierod section. The enlarged sections bear on half-cylindrical segments which transmit the load to the cross-head beams. The optimum configuration of the tierod head was determined by photoelastic investigation.

Main Hydraulic Cylinders: The main hydraulic cylinders are forged steel cylinders designed to receive 47¾-inch diameter rams. Hydraulic force is transmitted from the cylinders to the press structure through flanges which are integrally forged on the open end of the cylinders. The physical transition from cylinder wall to the flange is

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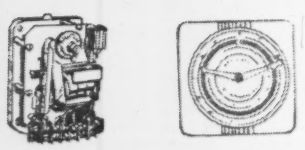

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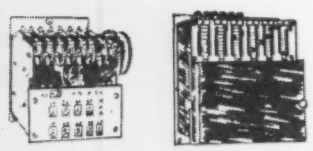

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Design Abstracts

a location where stress concentration is known to exist, its magnitude depending entirely on the design. Since failures in hydraulic cylinders have occurred at the junction of the flange and cylinder wall, a thorough investigation of the design used in this press was made. Three-dimensional photoelasticity was again the method used for investigation. Results confirmed the present design by showing relatively low stress concentrations.

Cylinder Holding Ring: A steel casting is employed to transmit the hydraulic effort from the main cylinder flange to the parallel structural beams of the press. Because of space limitations this casting is somewhat complex in its configuration. The determination of design adequacy by analytic methods must be based on many simplifying assumptions. Investigation of the cylinder holding ring was therefore accomplished by experimental model testing.

Cast aluminum models, 1/6 scale, were employed. The first three models were made from aluminum alloy T-356 because of its excellent casting properties. These models were first tested with brittle lacquer coatings to determine the direction of the principal stresses and were finally tested with SR-4 strain gages. Two of the T-356 alloy models were loaded to destruction, the first failing at a load of 400,000 lb and the second at a load of 470,000 lb; the latter being 1½ times the equivalent design load for the prototype. However, elongation of the T-356 alloy was much lower than that to be expected with the cast steel in the prototype. Failures of these models were definitely brittle.

To provide a closer approximation to the elongation properties of the steel to be used in the prototype, models were then cast in aluminum 220 T-4. One of these high-strength alloy models was first tested in the elastic range by observing strain gage readings during loading. It sustained a load of 907,000 lbs before failure. This is about three times the equivalent design load for the cast steel prototype. By performing these tests nothing was left to chance; and the ade-

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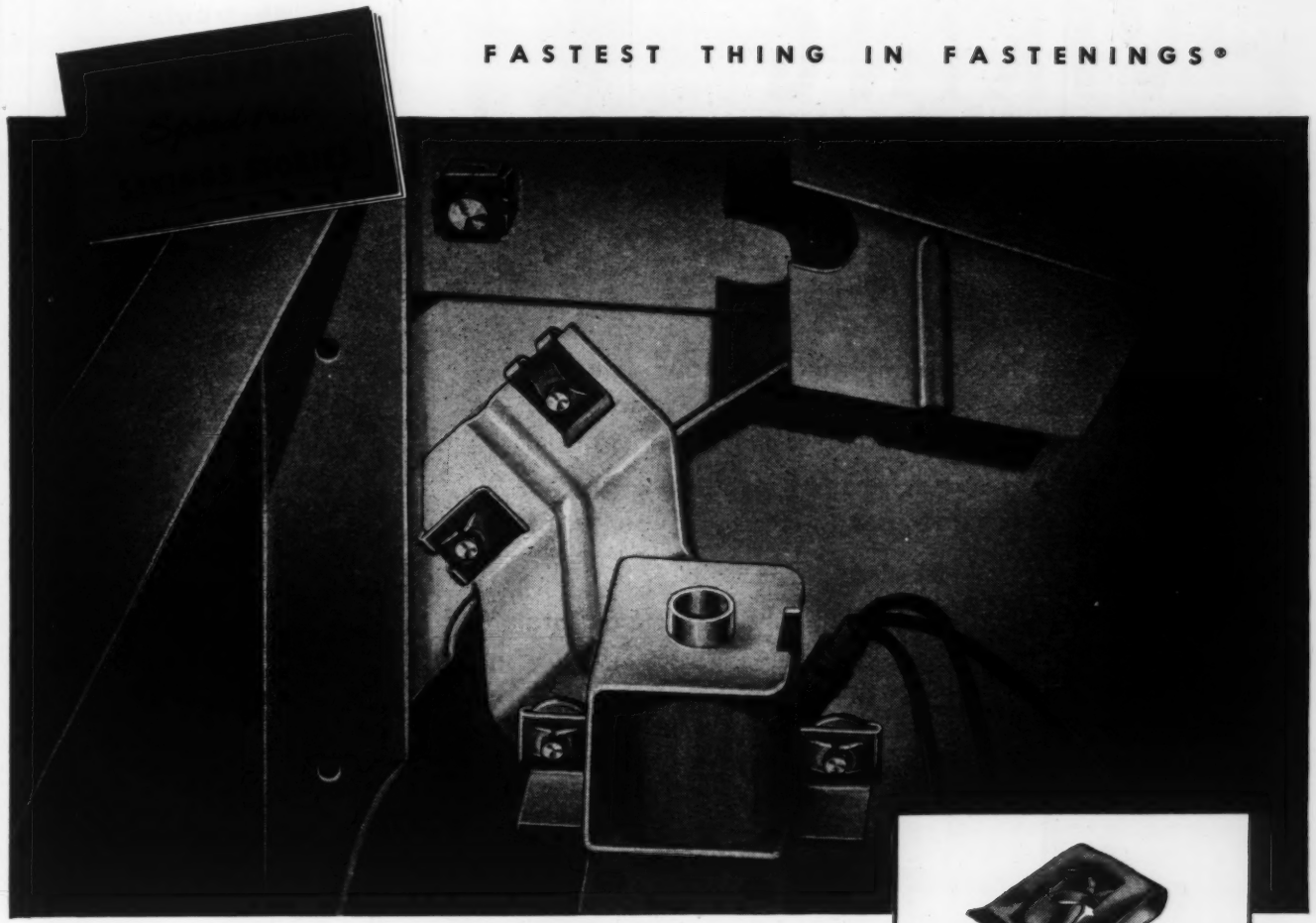

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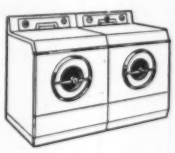

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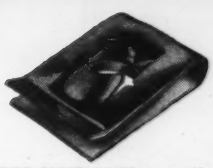

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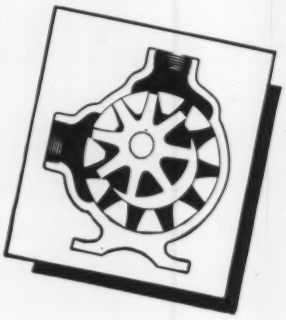

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Automatic Safety Controls: Notwithstanding extreme care and caution in operating the press, nor the diligence to obtain a safe and foolproof design, malfunction of either mechanical parts or of the hydraulic control system can cause serious damage to the structure unless adequate safety devices are employed. To remove the element of human error, automatic safety controls have been devised which will stop operation of the press and simultaneously unload the hydraulic system to prevent serious damage. Strain gages are used as detectors and monitors of stresses in the main tierods of the press. Not only are the absolute values of strain monitored but an electronic control system will also monitor values of strain rate so that for any critical combination of strain and strain rate, the press will automatically be shut down and protected. In this connection, it is essential that the time response of the control system be in accordance with that dictated by the study of the dynamic behavior of the press.

From a paper entitled "Design and Analysis Features of the

Design Abstracts

World's Largest Forging Press" presented at the ASME Annual Meeting in New York, N. Y., December 1952.

Precipitation Hardening Steels

By Gordon A. Fairbairn

North American Aviation Inc.
Los Angeles, Calif.

DESIGN demands for materials having better combinations of properties are always increasing as performance characteristics go up. New materials are constantly being investigated in order to meet these demands. In the selection of a material for an aircraft design there are many factors which must be considered before a choice is made. Normally the major factors are: (1) strength, (2) corrosion resistance, (3) fabrication, and (4) cost. It is not always possible to provide a material having properties which satisfy the designer in every respect and a compromise is necessary. For example, it may be necessary to sacrifice some strength in order to provide a material having sufficient corrosion resistance, or formability to permit fabrication.

One group of comparatively new alloys now being used on production designs are the precipitation hardening type stainless steels. Our experience has been mainly limited to three grades; namely, 17-4PH, 17-7PH and stainless "W" (AISI Type 322).

17-4PH: Essentially a heat-treatable iron-base bar and forging alloy, 17-4PH contains 16.5 per cent chromium, 3.5 per cent nickel, 3.5 per cent copper, and 0.35 per cent columbium + tantalum. Investigation of 17-4PH was prompted by the desire to find a material to replace AISI 416 stainless steel, which does not have satisfactory corrosion resistance for our applications and had proven troublesome with regard to consistent heat treat response. Typical applications under consideration were machined parts requiring a high degree of strength and corrosion resistance.

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Design Abstracts

or having shape or service requirements such that plating could not be used to increase the corrosion resistance.

One application in this category is a shimmy damper assembly for a Navy airplane. A material is required which is resistant to salt air corrosion and has a tensile strength of 180,000 psi. The part acts as a hydraulic cylinder and the inside diameter must provide a surface suitable for rubber "O" ring seals. Since this surface is exposed to marine atmospheres and cannot be readily plated, it is necessary to use a material having adequate inherent corrosion resistance. The 17-4PH alloy fulfilled the material requirements. Results of salt spray tests indicated the heat-treated alloy had a corrosion resistance comparable to the 18-8 stainless steels. After a 1000 hour exposure in a salt spray made up of 20 parts of salt to 80 parts of water no evidence of general corrosion was found.

Distortion Minimized

Untreated 17-4PH has a hardness of Brinell 286-337. It can be heat-treated to a tensile strength of 180,000-210,000 psi by precipitation hardening at 850-900 F for one hour, followed by air cooling. Because of the relatively low temperature required for hardening and the absence of a drastic quenching operation, distortion from heat treatment is not a problem. It is usually possible to finish machine parts prior to heat treatment. The dimensional change occurring during hardening is very slight, being a contraction in the order of 0.0005-inch per inch of length. The heat treating operation produces a discoloration on the surface of 17-4PH which can be removed by a 10-15 minute immersion in a nitric-hydrofluoric acid solution, or by a light sandblasting.

Inasmuch as 17-4PH is a ferromagnetic alloy, it is possible to magnetically inspect finished parts. This type of inspection has been required on some applications but it has not proved to be very satisfactory as the microstructure of heat treated 17-4PH tends to produce m-

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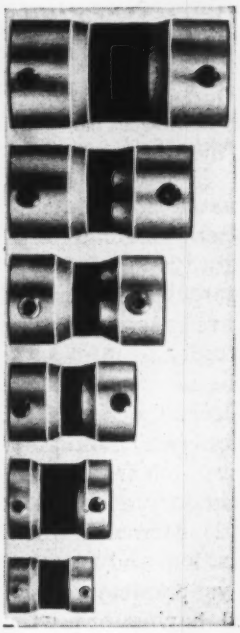

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dications which are often confused with indications of actual defects. In this connection, microstructural studies on the alloy have indicated a tendency toward banding which has an undesirable effect on transverse ductility. In view of this tendency, usage of 17-4PH is being limited to applications where low transverse ductility would not be detrimental. Some typical applications are an airplane wing hoisting eye assembly and a rocket igniter head. The wing hoist assembly is a loose equipment item for a Navy airplane and is stored aboard an aircraft carrier for the purpose of loading the airplane onto the carrier. This part is subject to rough handling in service and must withstand corrosion in marine atmospheres. The rocket igniter heads are used as firing pins for rockets. Points of the heads must be sufficiently hard to resist brinelling and also be resistant to corrosion in the rocket exhaust gas to provide a good electrical contact with the igniter buttons on the rocket.

17-7PH: This is essentially a heat-treatable iron-base sheet and wire alloy containing 17 per cent chromium, 7 per cent nickel and 1 per cent aluminum. The alloy was investigated in an effort to find a replacement material for ½-hard AISI 302 stainless steel sheet which was being used mainly in the fabrication of fuselage structures, such as frames, longerons, shrouds, skins and webs. The use of ½-hard 302 sheet imposed limitations on designs from the standpoint of strength and formability. The compressive yield strength of the ½-hard sheet is comparatively low in relation to the tensile yield strength, particularly in the longitudinal direction (parallel to the direction of rolling).

Further, since the strength of the sheet is obtained by work hardening during rolling, the fabrication of parts from this sheet must be done while the material is in the full-strength condition. This means the employment of heavy forming equipment in order to overcome the high yield strength of the material. The problem is further complicated by large variations in the yield

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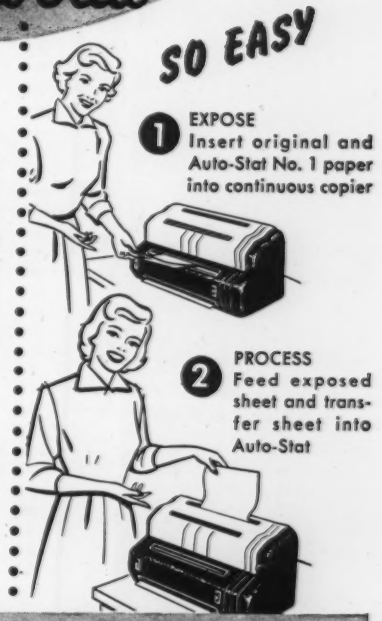
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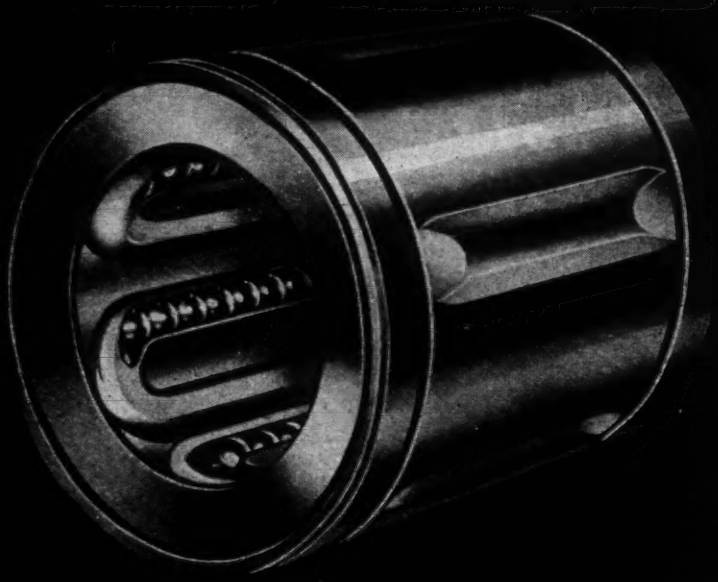

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strength of various lots of ½-hard sheet. Our experience has shown this variation to be as much as 40,000 psi. The result of the variation in yield strength is to produce different amounts of springback in the formed parts.

It is not possible to obtain consistent results on forming dies and therefore much handwork by shop personnel is needed to obtain dimensionally acceptable parts. A further problem encountered with ½-hard 302 sheet is the inability to shrink the material in forming. Buckling results on the compression flanges. In view of these problems, we wanted to find a material with equivalent corrosion resistance which could be formed in the soft condition and subsequently hardened to the higher strengths required without excessive warpage. The 17-7PH sheet alloy provided such a material.

High Tensile Strength

We have largely replaced ½-hard 302 sheet with 17-7PH sheet, particularly in applications where considerable forming is required. In comparison with the ½-hard sheet having a design allowable tensile ultimate strength of 150,000 psi, and an allowable tensile yield strength of 110,000 psi, the heat-treated 17-7PH sheet has an allowable tensile ultimate strength of 180,000 psi, and an allowable tensile yield strength of 150,000 psi. Further, 17-7PH provides the designer with a compression yield strength of 150,000 psi irrespective of grain direction as compared with the 80,000 psi (transverse) and 110,000 psi (longitudinal) values which must be used with the ½-hard 302 sheet.

The heat treatment procedure being used for 17-7PH is a transformation treatment for ½-hour at 1400 F followed by cooling to 60 F, and then an aging treatment at 1050 F for one hour followed by air cooling to room temperature. Warpage from heat treatment is normally not a problem, except in the case of large parts. Warpage occurs mainly during the 1400 F treatment with little change taking place during aging. Fortunately,

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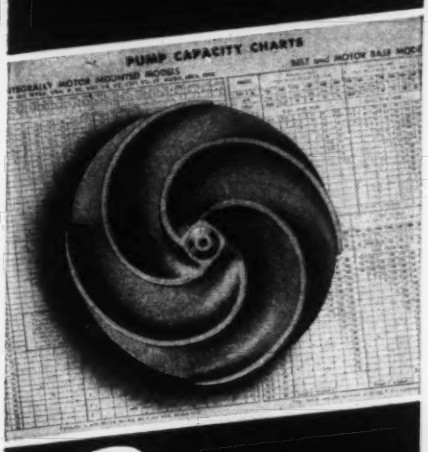

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the alloy does not harden appreciably during the 1400 F treatment and warped parts can easily be reworked prior to age hardening.

A typical routing for 17-7PH parts would be (1) form, (2) heat treat at 1400 F, (3) straighten, (4) heat treat at 1050 F and (5) check against template. A dimensional change amounting to a growth of approximately 0.004-inch per inch of length occurs during the transformation heat treatment. On large parts this growth is a problem which must be considered in designing forming dies in order to obtain parts within the dimensional tolerances. The aging treatment produces a shrink in dimensions of approximately 0.0003-inch per inch of length, which in sheet-metal parts is normally of no concern.

Spotwelding and seamwelding are being successfully performed on 17-7PH sheet using machine settings comparable to those used with ½-hard 302 sheet. This phase of fabrication is done on material in the fully heat-treated condition and produces joint strengths approximately equivalent to those obtained with ½-hard 302.

Aging Relieves Stresses

Typical applications where 17-7PH is being used are bottom and side frames of fuselage structures and also in the form of wire parts. As a wire material, it offers the designer a corrosion-resistant wire which can be heat-treated to a tensile strength comparable to music wire. In order to obtain maximum strength, the wire is procured in the cold worked condition (approximately 60 per cent reduction) and fabricated into parts. The formed parts are then hardened by aging at 850 F for four hours. The age hardening treatment serves the additional purpose of relieving the forming stresses.

One application for 17-7PH wire is a safety pin used in a canopy ejection mechanism for pilot emergency bailout. In service, this pin must be pulled out of the ejection mechanism while under heavy side loads from a spring-loaded firing plunger. It is important that the safety pin have sufficient strength

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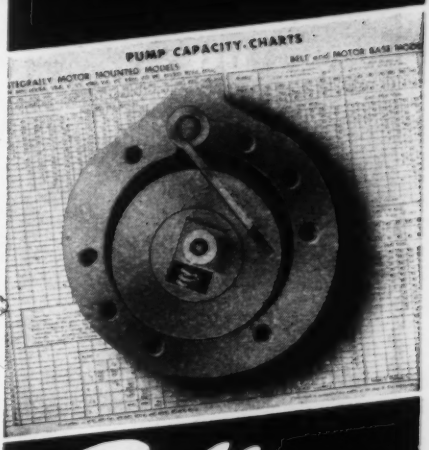

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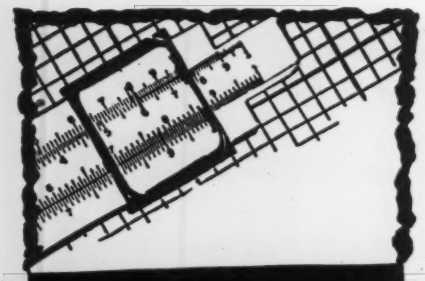

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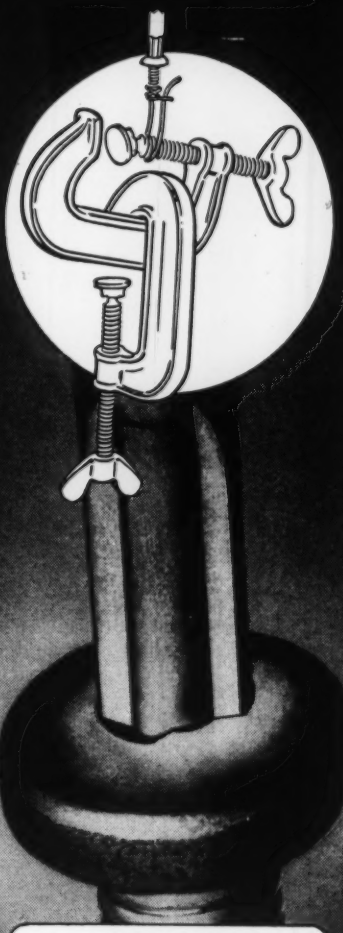
to resist plastic bending and sufficient hardness to resist scoring, which would prevent its being removed from the firing mechanism. Originally nickel-plated music wire was used for this part but was found to be unsatisfactory in functional tests as the nickel plate tended to peel off and thereby hinder the removal of the pin. The 17-7PH wire was tested and found to be entirely satisfactory.

Stainless "W": A heat-treatable iron-base alloy, stainless "W" contains 17 per cent chromium, 7 per cent nickel and about 1 per cent aluminum plus titanium. The alloy is heat treated from the annealed condition to a tensile strength of 180,000-220 000 psi by precipitation hardening for one hour at 950 F. Stainless "W" was investigated along with the 17-7PH as a possible replacement for ½-hard 302 sheet. In comparison with 17-7PH, it was found to warp less during heat treating, but was less ductile than 17-7PH in the annealed (as received) condition. This lower ductility made it necessary to limit its use for production parts to those applications which required only a limited amount of elongation in the forming operations. For example, it was not found satisfactory for strength forming except for limited contours. Stainless "W" is not being used by us at the present time, pending the development of better techniques for producing sheet, particularly in the lighter gages.

In summarizing the advantages realized through the use of precipitation hardening stainless steels, it can be said that the aircraft designer has been provided with a material having an inherent corrosion resistance adequate for aircraft applications combined with mechanical strengths comparable to those of highly heat-treated low-alloy steel. The utilization of these precipitation hardening steels has resulted in considerable savings in man hours and tooling costs.

From a paper entitled "Precipitation Hardening Steels Show Advantages in Aircraft" presented at the SAE National Aeronautic Meeting in Los Angeles, Calif., October 1952.

UNITED
CLUTCH HEAD®
SCREWS



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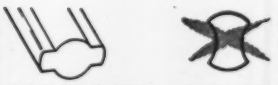

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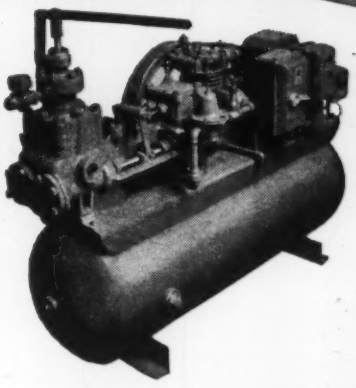

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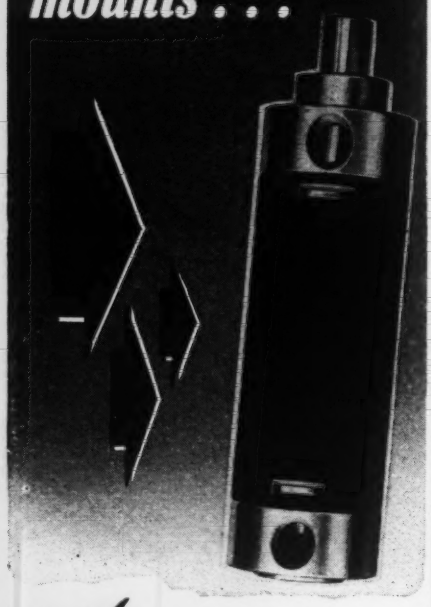

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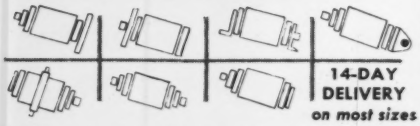

Because the end plugs are tapped for universal mounting, any one type or combination of mounting brackets can be used to install an O-M Cylinder . . . *without disassembling or changing the cylinder.* Interlocking mechanism eliminates projecting end caps and tie rods, assuring better alignment and friction-free performance. Thus, O-M Cylinders fit where others won't . . . require ⅓ less space than conventional type cylinders of the same bore . . . are easily removed, inspected, repaired.

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Power Driven Conveyor: For automatically moving stampings between progressive operations or for conveying scrap from press to tote boxes or conveyor belt. Portable, built in standard sizes of 6, 12 and 18-inch widths and 6, 11 and 16-foot lengths. Belts available with or without cleats and fabricated from rubber, cotton, stitched canvas or wire mesh. Equipped with heavy-duty, 110 or 220-v, 25 or 60-cycle gearhead motors. Special sizes available. *Sage Equipment Co., Buffalo, N. Y.*

Hydraulic Lift Stacker: Model S-400 is foot operated, lifts ¼-ton loads to maximum elevation of 58 in. Platform moves 2½ in. upward with each stroke of foot pedal; lowers automatically to any level at any speed. Raised height is 80 in.; lowered height, 50 in. Minimum fork height, 4 in.; overall width, 24 in.; fork length, 27 in.; fork width, adjustable maximum, 24 in.; floor clearance, 1 in. Swivel casters, all-steel construction. *Port-A-Lift Co., Bay City, Mich.*

Pallet Trucks: Powrworker line is battery powered, with a capacity rating up to 6000 lb. Can be supplied with pallet forks to handle any size pallet, either single or double faced. Two models available, one arranged for single tray (1 by 6) layout of battery, the other for double tray (2 by 3). Feature double hoisting cylinders for lifting loaded pallet, motor-in-wheel drive, full time delay control with all contactors interlocked for smooth progressive speed positions, positive safety-spring return handle which applies brake and cuts off power, and a bumper guard located high to avoid operator injury. *Clark Equipment Co., Buchanan, Mich.*

Hydraulic Lift Hand Truck: Capacity, ¼ ton. Designed for transporting and positioning at machines and work stations. Load is placed on platform resting on the

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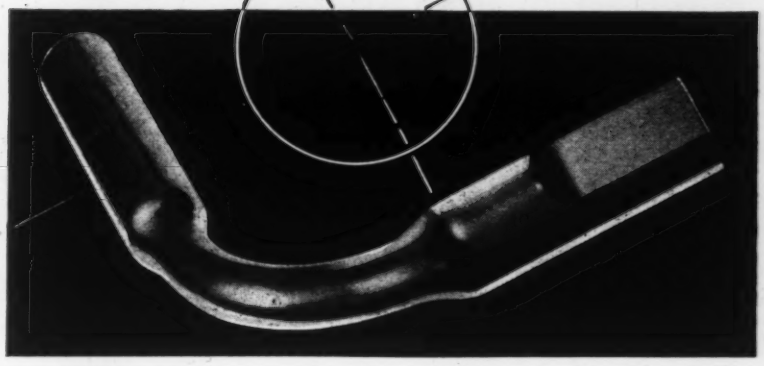

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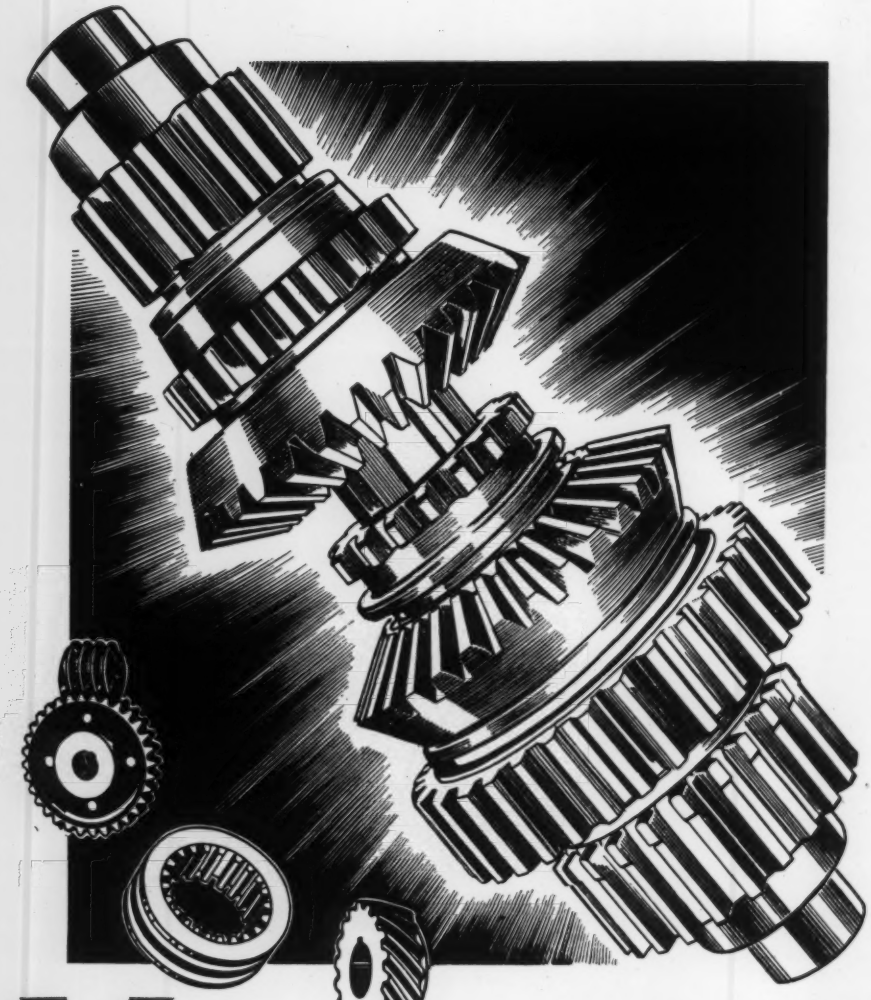

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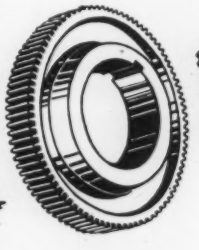

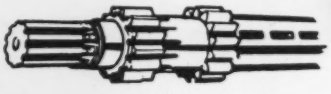

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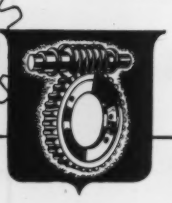

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New Machines

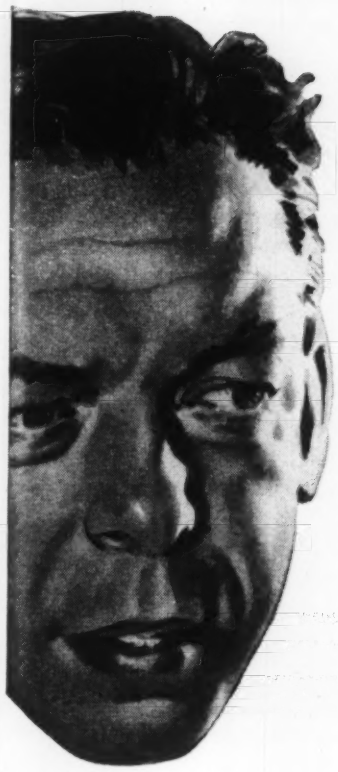
floor and is raised by actuating a foot pedal. Hand release lever regulates descending speed from slow to rapid to level desired. Can be equipped with specially designed platforms or forks. *Port-A-Lift Co., Bay City, Mich.*

Hydraulic - Electric Lift Truck: Capacity, 1000 lb. Manually propelled; electric lift is actuated by piston type hydraulic pump, powered by 6-v electric motor. Current is supplied by automotive type storage battery equipped with battery charger for overnight charging. Will raise 1000-lb load from floor level to a height of 4 ft in 15 sec. Material platform measures 23 by 24 in. Overall height, 64 in.; base area, 29 by 34 in. *Century Products Co., Minneapolis, Minn.*

Metalworking

Stamping Press: Model C-30 Flexopress, with capacity of 30 tons. Has integral feed rolls infinitely adjustable through overrunning clutch for 0 to 12-in. feed. Ram and connecting link are of high-strength, light alloy material. Ram is contained on multiple ball bearings operating in hardened and ground tool-steel raceways. Roll lift is adjustable 0 to ¼-in. Accommodates materials ranging from 0.002-in. thick aluminum foil, plastics, etc., to heavy metals within capacity range. Speed is infinitely adjustable from 110 to 450 strokes per minute. Platens are accessible on three sides. In automatic operation, coil stock feeds from the rear through the open back. *Precision Welder & Flexopress Corp., Cincinnati, O.*

Concentric Grinder: Four-inch capacity, for grinding outside diameters of workpieces such as antifriction bearing races or rings for precision mechanisms to extremely close limits of concentricity. New method of work holding prevents out-of-roundness which may be present in the bore from producing out-of-roundness of the OD. Parallelism with the face is assured within close limits in grinding grooves or raceways because of work holding and driving method. New work holding principle utilizes a revolv-

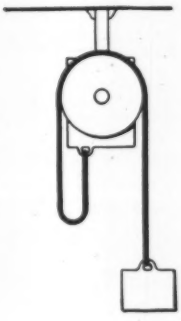


TENSION LINKAGE

WHAT'S THAT?

Some designers have been asking us what we mean by the term "tension linkage." We use it to describe any chain application in which the linear movement of the chain is not continuous in direction. The predominant feature of a tension linkage application is that the chain need not be formed as an endless chain belt.

There is a wide variety of possible tension linkage applications.



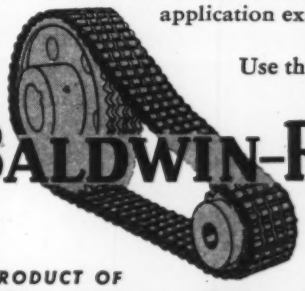
here's one example

Suspension of the load on a chain hoist. The load is lifted or lowered by the rotation of the sprocket. One end of the chain is permanently anchored as indicated. The free end is fastened to the object to be lifted or lowered. The sprocket is driven by hand power or motor power through gearing. The slack side of the chain usually hangs freely, thus providing 180° wrap on the sprocket.

here's another one

Reposition of a shaft that has been rotated through a limited angle. The shaft is turned clockwise (as shown in the illustration) during some operation of the associated equipment. The resulting compression of the spring provides the energy necessary to return the shaft to its original position. In many cases of this type, operation is frequent and high shock loads are encountered, so *chain* is the answer.

Our Bulletin No. 51-10 contains complete details on why Baldwin-Rex® Roller Chains, Leaf Chains and Block Chains are ideal for tension linkages. It also contains application examples and tables of weights, strengths and dimensions. Use the coupon to send for it today.



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A power drive flexible shaft undergoing a fatigue test in S.S.White's inspection and research laboratory.

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ing face plate which is a permanent magnet. Workpiece revolves about an arbor which has two wear-resistant strips spaced above and below the horizontal centerline on the side of the bore nearest the grinding wheel. In operation, the work arbor is moved alongside and near the center of the revolving face plate. A 3-hp motor drives a 16-in. diameter grinding wheel. Microsphere spindle bearings are used in both wheel head and work head. Hydraulic rapid infeed and continuous hydraulic slow grinding feed are used to position and feed the wheel during grinding cycle. *Landis Tool Co., Waynesboro, Pa.*

Hydraulic Plain Grinder: Churchill Model BW, 10 by 36-in. cylindrical machine. Operates on either traverse or plunge grinding. Equipped with self-adjusting Hydrauto grinding wheel spindle bearings; has nitralloy spindle and pump lubricated bearings. For plunge cut grinding, table can be reversed on extremely short strokes down to ⅛-in. Workhead is driven by variable-speed motor, current for which is supplied by a generator incorporated in the machine. Electrical controls are water and oil proof; all motors are mounted outside body of machine to avoid vibration. Can be supplied with full hydraulic auto-sizing wheel head including diminishing feed to size or with Churchill Fulcro-Sizer fine feed, making machine fully automatic. *British Industries Corp., International Machinery Div., New York, N. Y.*

Welding Torch: Lightweight Heliarc HW-13, for heavy-duty machine welding, can be mounted on any machine carriage that provides proper speed control for repeated straight-line, shape, girth seam or portable welding operations. Special gaskets prevent gas leakage; design also minimizes stub loss of tungsten electrodes. Torch body, welding head and gas cup are cooled by water passages inside torch. Water flows through internal passages down to water jacket and gas cup and out again through power cable. Nozzles can be replaced without disassembling torch. Range of nozzle sizes provides gas for all operations requiring up to

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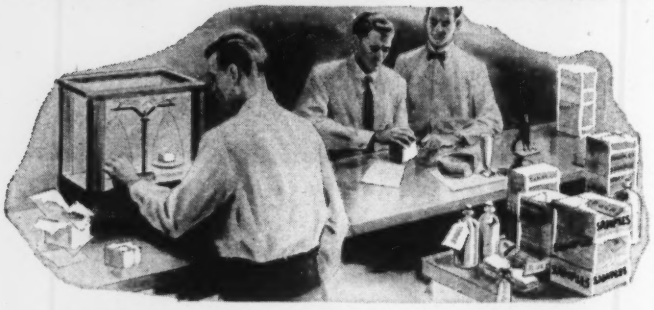

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500-amp welding current. Torch body is covered with plastic. *Linde Air Products Co., Div. of Union Carbide and Carbon Corp., New York, N. Y.*

Engine Lathe: Extra heavy 48-in. model redesigned for more power and rigidity. Suited to heavy turning, facing and threading operations. Bed lengths run in 5-ft increments from 20-ft minimum up to any length required. Width is 46½ in. Bed has angular guide front way. Headstock is completely antifriction with precision dual Timken bearings on the spindle. Variable voltage drive provides wide range of spindle speed with three gear changes, two through internal face plate drive and one direct to spindle. Normal spindle speeds range from 1 to 144 rpm. Feed gear box provides threads ranging from ½ to 56 per inch. Diameter of lead screw, 3½ in.; diameter of tailstock spindle, 7 in. Machine also built in 54 and 60-in. swing. *Simmons Machine Tool Corp., Albany, N. Y.*

Pneumatic Hydraulic Drill: No. 19-600 for heavy-duty drilling, tapping, reaming, spot facing, hollow milling and similar operations. Has maximum stroke of 6 in. and 1800-lb thrust with 80 psi air pressure. Can use up to 5-hp motor and a 1⅛ in. drill. Standard spindle has No. 4 Morse internal taper. Length of stroke is controlled by positive micrometer stop that is infinitely adjustable from 0 to 6 in. Depth can be held to within 0.0005-in. Rapid approach is at maximum rate of 5 in. per sec with infinite adjustment in length up to full stroke by means of a positive stop. Rapid return has maximum rate of 4 in. per sec. Feed rate adjusts infinitely from 0 to 180 in. per min. Back-feed valve, for locking out rapid return, permits using feed adjustment on return stroke for back spot facing and similar jobs. Built-in switches permit interlocking with other drill units or equipment. *Delta Power Tool Div., Rockwell Mfg. Co., Pittsburgh, Pa.*

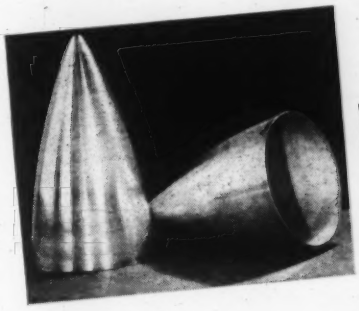
Pipe Threader: Power-operated Thred-O-Matic "44" threads, reams and cuts 4-in. pipe in 44 seconds. Equipped with die heads for pipe in 2½, 3, 3½ and 4-in. sizes. Adap-

ters available to handle ½ to 2-in. pipe. Has four hobbed jaws in front and four in rear which grip pipe tighter as torque is applied. Transmission has four speeds forward and reverse, which, coupled with two-speed motor, provides eight speeds forward. Flat blade reamer attached to die head cleanly reams inside of pipe during threading. Reamer may be removed for running threads. One screw simultaneously adjusts all dies for changing depth of thread. Set screw located behind each die permits adjustment of individual segments. Cutter mounted on front jaw housing allows operator to place fitting on pipe immediately after threading. Cutter is removeable for short nipples. Power is provided by two-speed, 3-hp motor operating on 220-v, 50-60-cycles. *Quijada Tool Div., Gaines-Collins, Los Angeles, Calif.*

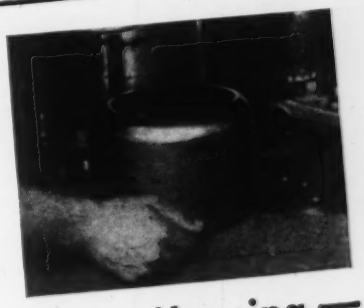
Power Notcher: For sheet material. Can make a notch as large as 6 by 6-in. in 16 gage sheet steel. Notches both larger and smaller than 90 degrees can be made, and some straight shearing jobs can be performed by making a few adjustments. Gages for adjusting depth and angle of notch are mounted on 12 by 18-in. work table. Production rate, up to 180 strokes per minute. Foot-actuated clutch leaves operator's hands free for work handling. Flywheel is driven by either single or three-phase ½-hp electric motor. Occupies floor space 17 by 28 in.; weighs 465 lb. *O'Neil-Irwin Mfg. Co., Lake City, Minn.*

Horizontal Boring Mill: Model No. 3B has fixed center and automatic cycle. Hardened high alloy steel spindle reciprocates through hardened steel bushings mounted in sleeve. Sleeve is contained at forward end in two precision Timken bearings, and rear-mounted third bearing floats. Feed mechanism is operated by hydraulic pump and fluid motor. System of valves and piping allows cycle adjustments within range specified. Changes of feed during automatic cycle are controlled by adjustable dogs contacting limit switches. Specifications include: spindle speed, 33 to 500 rpm by pick off gears; spindle diameter, 3 in; Morse taper

2 DIFFERENT FORMING PROBLEMS
2 PRACTICAL SOLUTIONS
By Means of Phoenixspun Processing



Tail Piece —
The Problem: To produce 50 units on temporary tools, for a military application — short-term delivery demanded. Piece formed from a flat bank. Due to bullet shape, the exceptional depth presented a difficult forming problem, with the depth of draw approximately 18" and a diameter of approximately 9". Produced in four weeks, including tooling, compared with four months for the deep-draw process. Low cost wood tools used for a majority of the five operations accounted for this extra speedy production.



Drawn Housing —
The Problem: Producing 1000 units per month, 7½" diameter by 5" deep, from 18 gauge steel. Piece was originally formed by the spinning process. After production was converted to deep drawing, unit labor costs on the job were reduced from 15 hours to only 1½ hours per 100 pieces, at the same time quickly amortizing the higher tool cost required for deep drawing.

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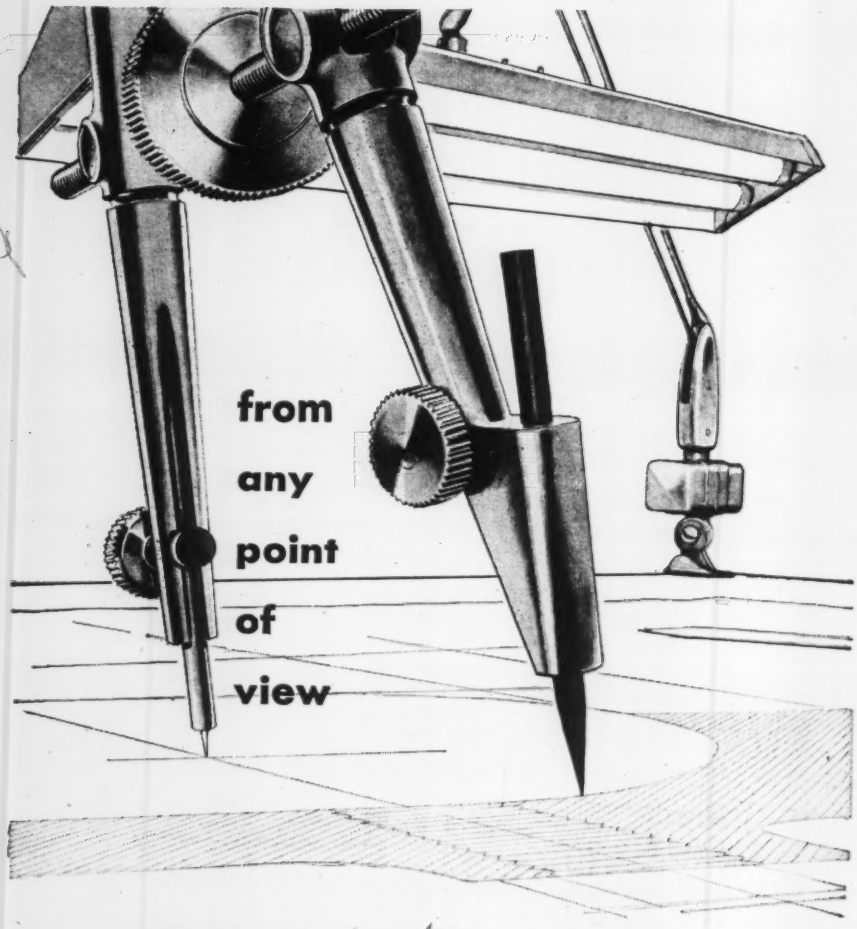

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New Machines

of spindle, No. 5; length of bar stroke, 10 in. *W. K. Millholland Machinery Co. Inc., Indianapolis, Ind.*

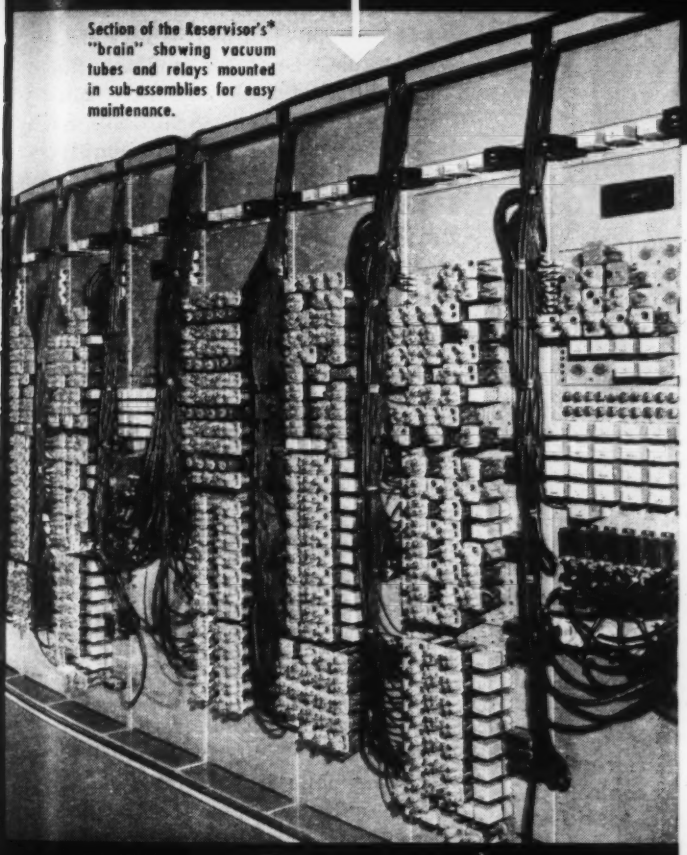
Universal Girth Welder: Has tilting table with variable rotation speeds. Columns which support table also support overhead platform for mounting power source and allied equipment. Table drive passes through two-speed, lever operated, disk clutch gear case. Both normal welding speeds and rapid traverse for positioning are possible. Table surface includes bored pilot hole as well as jig drilled and tapped holes for application of fixtures. Application of air, water and gas through center hole is possible without machine modification. Has 50-in. vertical saddle adjustment, 11-in. horizontal crossrail adjustment, 24-in. head mounting block adjustment, 300-degree table tilt, with a 20 to 1 table rotation ratio. Table will carry maximum load of 10 tons 6-in. eccentric 6 in. above the table. *Morton Mfg. Co., Muskegon Heights, Mich.*

Precision Tool Grinder: Double-end Style 44-A uses 6-in. cup-type wheels; sharpens tool materials such as sintered carbides, cast alloys and high-speed steels. Especially suitable for grinding carbide with diamond wheels because of smoothness and true-running characteristics. Sharpens all sizes of boring, turning and facing tools up to $\frac{5}{8}$-inch square or equal cross-sectional area. Features heavy steel base, large U-shaped tool rest tables, hardened steel plates. Tables can tilt to required angle; adjustment is read in degrees on scale. Coolant tank in base has large cleanout and drain opening. Wheel spindle is driven by balanced built-in reversible motor which permits the use of left and right-hand tools on the same wheel. *Ex-Cell-O Corp., Detroit, Mich.*

Plant Equipment

Steam Cleaner: Model BOE-600S can discharge up to 540 gph of pressure detergent spray and up to 540 gph of hot or cold pressure rinse simultaneously. Equipped with 60-gal detergent concentrate

CLARE RELAYS



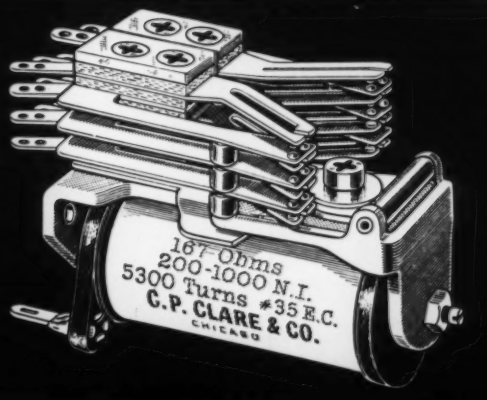
Section of the Reservisor's* "brain" showing vacuum tubes and relays mounted in sub-assemblies for easy maintenance.

IMMEDIATE INFORMATION on reservations for American Airlines' 1000 flights a day is available to airline personnel through the use of The Teleregister Corporation's Magnetronic Reservisor,* the first completely automatic reservations system.

With its 1500 tubes and 1400 CLARE relays, the Reservisor* is also a high-speed computer, a storage and filing system, data transmission system, display device, and a logging or recording unit.

In their vast experience with electrical controls, Teleregister's engineers have acquired a knowledge of relays that is wide and deep. The importance which they attached to selecting the best possible relays for the Magnetronic Reservisor* stands out in these their own words, "Choice of components, equipment layout, and circuitry were aimed at reliability. First of all, the incidence of trouble should be held to the minimum. This has been accomplished by using only the finest components and by using a sturdy relay instead of a vacuum tube wherever possible." Their deliberate choice of CLARE relays is therefore charged with meaning for industrial designers.

CLARE sales engineers are located in principal cities to cooperate in the development or "custom-building" of relays to meet your most difficult design applications. Call them or write: C. P. Clare & Co., 4719 West Sunnyside Avenue, Chicago 30, Illinois. In Canada: Canadian Line Materials Ltd., Toronto 13. Cable address: CLARELAY.



Clare Type J Relay of which 1400 are used in Magnetronic Reservisor* is an extremely compact and lightweight relay.

*Trade Mark of The Teleregister Corp.

CLARE RELAYS

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The precision-wound coil is fixed to the outer end of the mounting on the back of the dial. A pen with an extended arm is attached to a shaft that is spot welded to the inner end of the coil. Changes in room temperature cause the element to react in a coiling or uncoiling motion, thus causing the pen to move left or right, recording the temperature. At the same time a spring wound clock rotates the chart to synchronize the time with the temperature reading.

The accuracy of this multi-range recorder is dependent upon precision manufacturing and assembly methods. We fabricate this type of coil from precision-rolled strip stock in a controlled-temperature department. We also provide our 29 types of thermostatic bimetal in elements to customer design, in strips, random coiled lengths or welded or brazed sub-assemblies. Before proceeding with your next design, consult our Application Engineers or write for our 32-page booklet, "Successful Applications of Chace Thermostatic Bimetal," containing condensed engineering data.

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New Machines

tank and 40-gal fuel tank. Will operate for 4 hours continuously at maximum load. Vapor generator operates with over 80 per cent thermal efficiency; pressure atomizing burner system operates on either kerosene, fuel oil, distillates, or gasoline. Supplied with cleaning gun, rinse gun, two sets of delivery hoses and 150 ft of heavy duty electrical cable. Operates on 220-v, 60-cycle, single-phase current. Machine is 48 in. high, 88 in. long, 34 in. wide; weighs 2000 lb empty. *Clayton Mfg. Co., El Monte, Calif.*

Jet Cleaner: Speedylectric Hydrajet for heavy-duty cleaning jobs. Provides hydraulic jet of 4 to 8 gal of scalding hot soap and water per minute at nozzle pressures up to 600 psi. Suitable detergents or solvents may be introduced intermittently or continuously in any desired, automatically controlled concentration. Installation requires connections to existing steam lines and electric power sufficient for 3-hp motor. *Livingstone Engineering Co., Worcester, Mass.*

Oil Mist Controller: Precipitron recovers coolant oil from mist and smoke generated by high-speed cutting, grinding, milling and similar machining operations. Available in two models—Type PO-6 with air handling capacity of 600 cfm, and PO-12 with capacity of 1200 cfm. Completely self-contained—cabinet houses oil-particle charging and collecting elements with their high-voltage power pack, motor driven fan, duct connection and oil sump. Totally-enclosed fan motors are three-phase, fractional-horsepower, ball bearing, prelubricated, for 220 or 440-v service. Power pack operates from single-phase, 115-v line and consumes less than 60 watts when operating. Model PO-6 is 55 in. high, 22 in. wide, 24 in. deep; weighs 265 lb. PO-12 is 63 in. high, 31 in. wide, 27 in. deep; weighs 390 lb. *Westinghouse Electric Corp., Sturtevant Div., Boston, Mass.*

Testing and Inspection

Air Meter: Model H operates on 90 to 135-v, ac; is accurate to ±2 per cent. Velocities are measured by means of a sensitive thermopile located in the probe. Features dual

velocity ranges of 10 to 750 and 750 to 5500 fpm, and expanded low-range scale and ease of operation—one switch is used to turn on the current and select range while an adjustment of the calibration knob compensates for line voltage variations. Adaptable to applications requiring permanent or remote installations. Current set meter provides continuous calibration check. Has recorder binding posts. Any recorder which operates on 10 mv or less with a low current drain can be used with the instrument. Compensated for rate of temperature change; readings are direct and instantaneous. *Hastings Instrument Co., Hampton, Va.*

Altitude Chambers: Standard TenneyZphere units provide vacuum conditions simulating altitudes from sea level to approximately 80,000 ft, as well as high and low temperatures and variable relative humidity conditions. Temperatures range from 200 to −100 F; relative humidities, from 20 to 95 per cent. Time required to heat from ambient temperature to 200 F is 60 minutes; time required to cool to −70 F is 2 hours. Average rate of climb to 50,000 ft is 3000 fpm. Features include preset control for any desired altitude, terminal lead-in panel with eight terminal posts and four copper constantan thermocouples, low temperatures of −70, −85 or −100 F, 200-w dissipation at lowest specified temperature, standard instrumentation for wet and dry-bulb temperatures, sealed multipane viewing window, glareless lighting of test space, and full access to chamber interior. *Tenney Engineering Inc., Newark, N. J.*

Measuring Microscope: Pocket-sized, 50-power Optometer has engraved scale mounted in body tube which reads directly to 0.002-in. Estimations can be made to 0.0005-in. Precision, achromatic lenses, which are fully corrected for color and spherical aberration, result in a sharp image up to edge of field of vision. Can be used for measuring crest and root widths of threads; pitch and depth of threads; radii of points and corners; width of slots, chamfers and grooves; dimension from a center punch mark to a

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Woodworking

Radial Arm Saw: Model GE has power cross feed. Besides normal straight cut-off, it can also make miter cuts, bevel cuts, and compound miter cuts. Cuts materials up to 2 by 18 in. without adjustments in air feed mechanism. In operation, foot control valve is pressed, held until desired cut has been made, then released. Two-way action of air cylinder immediately returns saw to idle position. Air-feed cylinder is quickly detached by removing only one stud, placing machine in manual operation. *DeWalt Inc., Lancaster, Pa.*

Electric Hand Drills: "General Duty" Model 107 with ¼-in. chuck is designed for all-around intermittent use. Has pistol-grip with pushbutton lock. Compound reduction gears deliver maximum power to spindle. Idle speed is 2000 rpm. Size, 8¼ in. long, 2¾ in. wide; weighs 3 lb, 6 oz. "Special Duty" Model 109 with ½-in. chuck is for intermittent production use which requires power to penetrate metals and other resistant materials, as well as wood. Spade handle at rear can be changed to vertical or horizontal position, or removed entirely. Lower, full-hand grip has trigger lock-bottom switch. Removable auxiliary handle which can be mounted on top or side of drill enables operator to increase pressure and control torque. Has double compound reduction gears; idles at 450 rpm. Size without rear handle. 10¾ in. long, 3¾ in. wide; weighs 9 lb. *Porter-Cable Machine Co., Syracuse, N. Y.*

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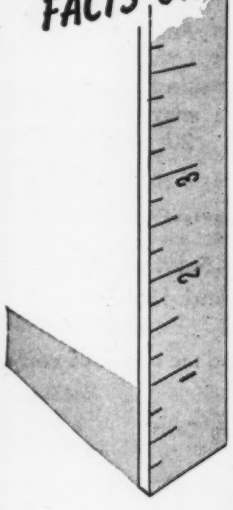

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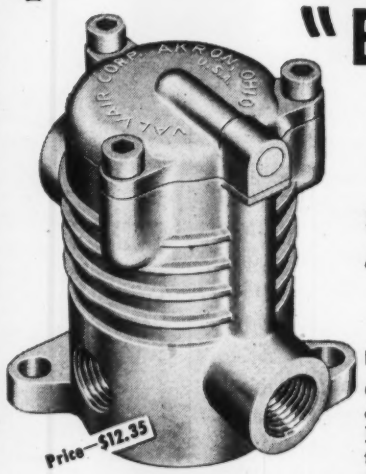

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